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TECHNICAL REPORT ECOM-C0564-F

100 FOOT COLLAPSIBLE ROLL-UP ANTENNA MAST

FINAL REPORT

BY
FRANK B. KIESER

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UNITED STATES ARMY ELECTRONICS COMMAND • FORT MONMOUTH, N.J.

CONTRACT DAAB 07-67-C-0564

GENERAL ELECTRIC CO.

MISSILE AND SPACE DIVISION

PHILADELPHIA, PA.

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13. ABSTRACT <p>A collapsible roll-up antenna mast has been developed to erect a one and one-half pound antenna through jungle trees to a height of 100 feet above ground level. The mast can be erected as a cantilever to a height of forty feet. Erection to the full 100 foot height requires support from the tree limbs and branches. Also included is a light-weight reel for storage of the mast and to facilitate erection and retraction. The complete assembly weight, 17 pounds and is man portable.</p> <p>The mast is a tapered truss design that is fabricated almost exclusively from high strength fiberglass rods. The truss construction provides low wind drag, low visibility and high strength of the deployed mast.</p> <p>The report describes the analysis and design, fabrication, testing and operating instructions for the mast.</p>			

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100 FOOT COLLAPSIBLE

ROLL - UP

ANTENNA MAST

FINAL REPORT

REPORT NO. I, FINAL REPORT

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for

U.S. ARMY ELECTRONIC 3 COMPANY, FORT MONMOUTH, N.J.

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SECTION I

SUMMARY

This report presents the work performed for the U. S. Army Electronics Command by the Space Systems Organization of the General Electric Company under Contract DAAB 07-67-C-0564. The purpose of this contract was to design, fabricate and test two exploratory development models of a man-portable jungle antenna mast in accordance with Electronics Command Specification EL-CP-0500-0001.

The antenna mast system is shown in Figures 1 and 2. In its stowed configuration, it is a package 22 inches wide by 25 inches high by 10 inches deep. The complete assembly weighed 17 pounds. Two units were delivered on September 20, 1968.

The antenna mast is a reelable truss design which is fabricated from high strength fiberglass rods. The truss construction provides a light-weight high-strength mast that has low wind drag.

The mast can be erected to its full height of 100 feet by one man in less than five minutes once a suitable erection site is selected. Retraction is also accomplished by one man in about five minutes.

The mast, with a one and one-half pound tip mass simulating an antenna, has been erected to a height of forty feet in winds as high as fifteen miles per hour. It has remained erect when fully deployed through trees in winds up to 25 miles per hour. The second unit has been erected and retracted through trees one hundred times.

The reelable truss design developed in these two exploratory development models has demonstrated the following advantages:

1. High strength and stiffness to weight ratio;
2. Low wind drag;
3. Low visibility, particularly with the trees as a background;
4. The ability to include the antenna lead in conductors with the reelable mast.

One obvious concern for a truss type construction to be used through jungle trees is the possibility of snagging of tree branches and leaves in the truss openings. Some difficulty was experienced in the first unit, not in getting stuck in the trees, but in breakage of the diagonal elements in the truss. In the second unit, the design of the diagonal elements was modified and the size of diagonals was increased in some local areas. No breakage of diagonals was experienced in the one hundred erection and retraction cycles in trees performed on this unit.

It is also interesting to note that the mast was collapsed over a large tree limb so that the one and one-half pound tip mass hung several feet below the limb. As the mast was retracted from the ground, it slid smoothly over the limb until it popped out to its square cross section and the erection cycle was resumed. There was no damage to the mast.

Some joint wear resulted from the one hundred cycle test as noted in the test report. In any of the cases of diagonal breakage on the first unit or joint wear on the second, the mast always retained sufficient strength to withstand the required loading conditions. Any breakage or wear can be repaired to return the mast to its original strength.

Prior to this contract, experimental trusses had been made from spring wire. It is believed that the development under this contract has demonstrated the advantages to be gained from this type of structure and the unique advantages in the use of fiberglass rods. The techniques utilizing the high strength properties of the fiberglass in terms of joint design and forming fiberglass rods had to be developed with practically no previous experience to draw from.

Within the funding available under this contract, two complete units were fabricated and a significant amount of testing accomplished. Further development of this design would include

- a) Improved joint techniques on the mast for easier producibility and better wear resistance;
- b) Refinement of the storage reel design with consideration of a hard shell container to enclose the complete unit.

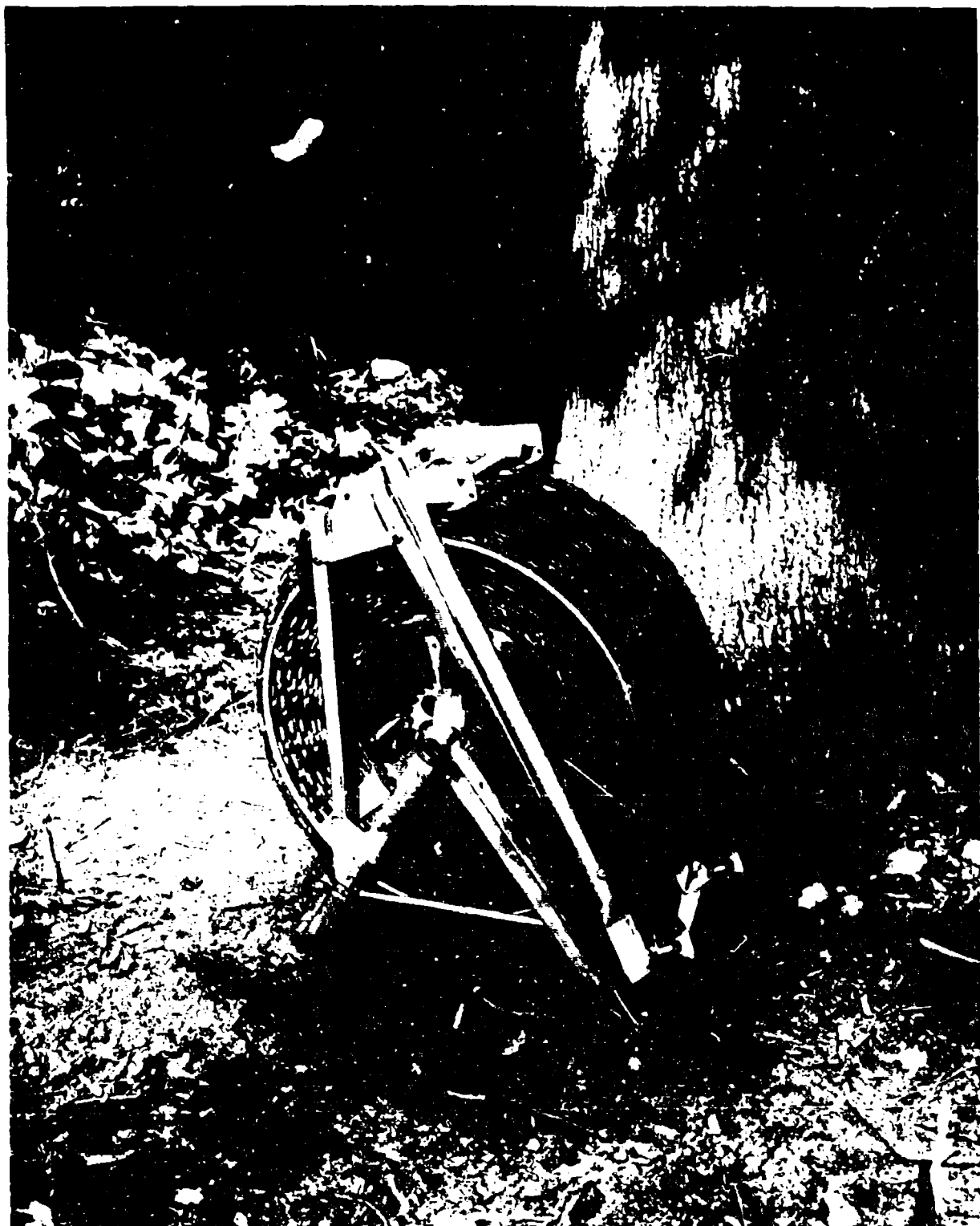
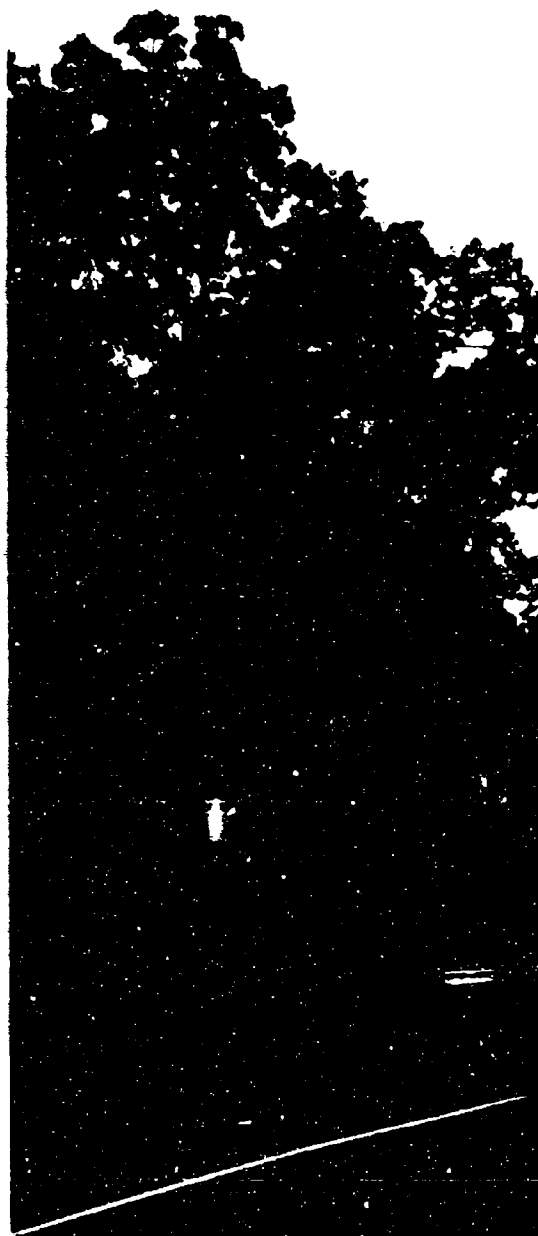


FIGURE 1. MAST IN STOWED CONFIGURATION



MAST ERECTED
40 FOOT CANTILEVER



MAST ERECTED
100 FEET THRU TREES

FIGURE 2

SECTION II

DESIGN

DESIGN REQUIREMENTS

The design requirements are contained in Electronics Command Technical Description EL-CP-0500-0001A. The mast is to be a man-portable assembly that can be erected by one man up through jungle trees and project out above the tree-tops. The tree limbs and foliage will give support to the mast. The mast is to be a reelable type, that is, one that can be deformed from its extended load carrying shape into a form that can be rolled up on a reel for compact storage. The mast is to be designed to support a one and one-half pound mass on the tip which simulates the antenna weight.

The mast is to be erected to a height of 40 feet in a five mile per hour wind. It will then begin to get support from the tree limbs. It will go up through the trees to a height of 75 feet and then project above the tree-tops for 25 feet giving a total height of 100 feet. The mast must remain erect in a wind of 10 miles per hour and must be able to survive a wind of 50 miles per hour. That is, if it collapses at a velocity below 50 miles per hour it must be reeled down without damage.

The upper 25 feet of the mast is to be a dielectric material. The total weight of the mast and storage reel is to be 15 pounds with a desired weight of 12 pounds. The assembly must be capable of 2,000 erections and retractions of the mast. It must withstand the environments of shock, vibration, humidity and high and low temperatures.

DESIGN APPROACH

The mast design is based on the General Electric deployable truss, which is described in detail later. Trade-off studies of different materials for the mast structure indicated that fiberglass rods with a modulus of elasticity of 5 million or greater were an optimum material for a light weight design. This would also meet the requirement of the upper twenty-five feet being a dielectric material and allow the entire mast to be fabricated from the same type material.

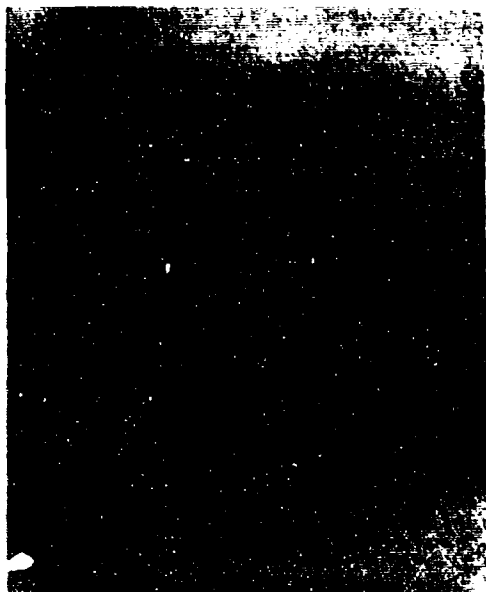
In addition to the specification requirements, there appeared to be other conditions affecting the design and performance of the mast. The degree to which the mast could be erected vertically by the operator was not specified but as will be shown later, this could be as significant a load factor as the wind loading. The type of reaction provided by the limb supports, that is, how stiff a reaction does the uppermost limbs provide, would also affect the loading on the mast. The resistance of the foliage to piercing would affect the column loading in the mast. No wind drag load applied by the antenna or its electrical lead-in was specified. The uncertainty of these conditions led to the approach of designing as much strength into the mast as could be provided within the weight and distributing this strength in an optimum fashion over the length of the mast. A maximum weight of 9 pounds was assigned to the mast and 6 pounds to the storage container.

DEPLOYABLE TRUSS

The concept of the deployable truss is to provide a truss type beam consisting of longitudinal tension and compression members interconnected with diagonal shear carrying members. The load carrying shape of

the beam can be deformed into a flat tape-like section that can be rolled on a storage reel. Two typical configurations are shown in Figure 3. There must be an even number of truss panels with a minimum of four that result in a polygon cross-section of the beam with the longitudinal members at the corners of the polygon. Hinges are provided at diagonally opposite corners of the polygon so that the cross-section can be deformed into a flat strip which can be rolled onto a storage reel. The arrangements and spacing of the longitudinal and diagonal members is such that when the beam is deformed to a flat tape, all of the longitudinal members are in the same plane so that they roll on the same radius resulting in only bending stresses in the longitudinals when rolled on the drum.

The original design for this mast was the circular truss shown in Figure 3, and consisted of eight longitudinal members joined by diagonals which were continuous between diagonally opposite longitudinals terminating in a hinged joint at the longitudinal. The diagonals, in their unstressed condition, maintained the deployed shape of the beam. For storage, the diagonals had to be deformed to a flat shape. This configuration had two basic disadvantages. Early tests of sample sections indicated that when stored flat and subjected to the high temperature storage condition (155°F), the section would not return to the fully deployed shape. Also, for any given beam cross sectional size, the sizing of the diagonal member was limited by the diameter which could be deformed to the flat section without overstressing. For these reasons, the design was modified.



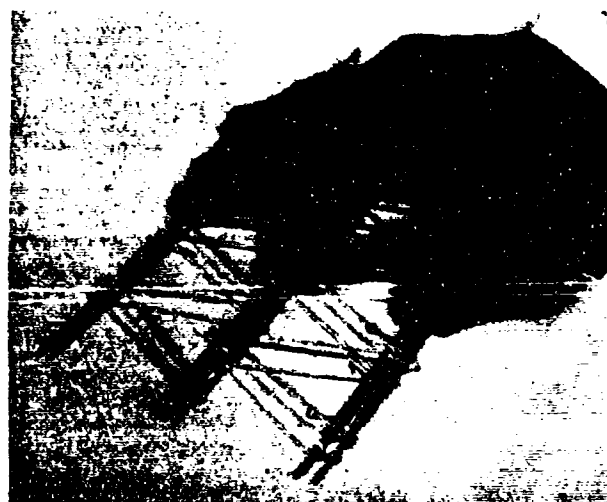
CIRCULAR TRUSS DEPLOYED



SQUARE TRUSS DEPLOYED



CIRCULAR TRUSS
FLATTENED FOR ROLLING



SQUARE TRUSS
FLATTENED FOR ROLLING

FIGURE 3

The design which overcame the above difficulties is the square truss, shown in Figure 3. It consists of four longitudinal members with the diagonals hinged at each longitudinal. Torsion springs provided the force to maintain the beam in a deployed rectangular cross section. Flexible cords between opposite corners of the beam restrain the section from deploying further than the rectangular section under the force of the torsion springs. This design with relatively simple fixturing allows tapering of the beam cross section, and sizing the diagonal members to suit the load applied. Standard techniques are available to fabricate the longitudinal members with a tapered diameter along the length. Using these techniques, a highly efficient beam can be fabricated.

The merits of a straight non-tapered mast versus the tapered mast described above were evaluated and the tapered design selected for the following reasons:

1. For equal mast weight of 9 pounds, the tapered mast was capable of withstanding twice the maximum bending moment of the untapered mast. The critical buckling load for the 40 foot cantilever column is twice as great for the tapered mast.
2. Because of the smaller cross-section at the tip of the mast, the applied bending moments from the wind load were reduced by 30%.
3. Because of the smaller diameter of longitudinals at the base of the mast, the storage reel diameter was smaller resulting in a difference in the maximum stored diameter of

25 inches for the untapered mast and 22 inches for the tapered mast. This would also reflect in a reduced weight of storage container for the tapered mast.

4. It was estimated that the complexity of fabrication of the tapered mast would be 25% greater than the untapered mast.
5. The importance of minimum weight for the unit and the uncertainty of loads that would be applied in actual operating conditions indicated that the additional efficiency of the tapered mast more than compensated for the increased complexity of fabrication.

MAST CHARACTERISTICS

The deployed mast is a box section truss in which both longitudinal and diagonal members of the truss are a circular cross section. As will be shown later, the strength required by the mast is primarily a function of the bending loads applied by the required design conditions. The bending strength of the mast is varied along its length in proportion to the applied bending loads. The bending strength is varied by

- a) Tapering the depth of the box section;
- b) Tapering the diameter of the four longitudinal members;
- c) Varying the spacing of the diagonals along the longitudinal members.

Early tests demonstrated that the basic mode of failure in the bending occurred by buckling the longitudinal members in compression between points where they are supported by the diagonal members. Nodal points in the buckling curve occurred at the diagonal attachments. The compressive

stress at which the buckling occurred followed the stress predicted by the Euler column theory with the column being pin ended between diagonal support points with an end fixity coefficient of 1.5.

The diagonal members must be of adequate diameter to resist the column load resulting from the shear loads in the mast, and as was later shown in testing, the need for adequate strength to resist breakage as the mast passes through the trees may also be a critical design condition. In this design the diagonal diameter is varied in steps along the length of the mast. The torsion springs which maintain the deployed shape must be of adequate strength to prevent the section from collapsing when a concentrated shear load is applied at the reaction points. The typical mast section sizing of detail members of the mast and the resulting characteristics are shown in Figures 4 and 5.

AERODYNAMIC DRAG

The aerodynamic drag of the mast was determined to follow the theoretical equation

$$D = \frac{1}{2} \rho C_d S V^2$$

where

ρ = air density - .002378

* C_d = drag coefficient - 0.8

S = total projected area of diagonals and
longitudinals - sq. ft.

V = wind velocity - ft/sec.

* Drag coefficient determined by test described in Section IV

MAST BENDING STRENGTH

The following physical characteristics determine the mast bending strength (see Figures 4 and 5):

D = depth of beam section

D_v = diameter of longitudinal member

L = length of longitudinal between diagonal supports

C = end fixity coefficient of longitudinal

* E = modulus of elasticity = 5×10^6 P.S.I.

I = section modulus

c = distance from neutral axis to outermost fiber

The following analysis is based on a section that is nearly square in cross section:

$$I = \frac{\pi^2}{4} d_v^2 D^2 \text{ (about any axis)}$$

$$c = D \sin 45^\circ = .707D \text{ (about diagonal axis)}$$

$$S = C \pi^2 E / (4L/d_v)^2 \quad * C = 1.5$$

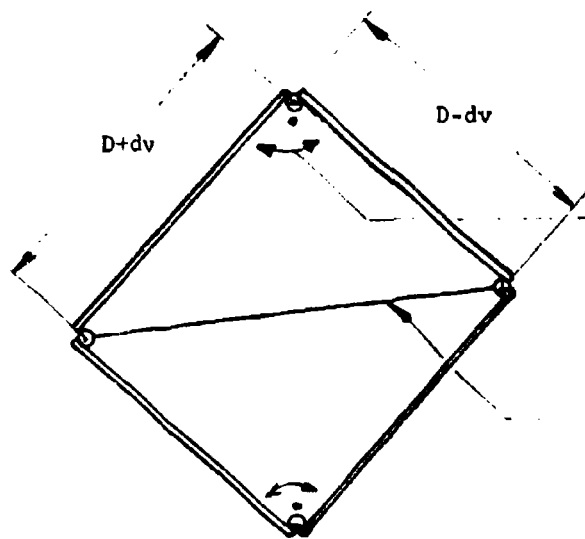
$$S = 1.5 \pi^2 E / (4L/d_v)^2$$

$$S = .925 E d_v^2 / L^2$$

$$M = S I / c$$

$$M = \frac{.925 E d_v^2 \times \pi^2 d_v^2 D^2}{4 \times .707 D \times L^2} = \frac{1.025 E D d_v^4}{L^2}$$

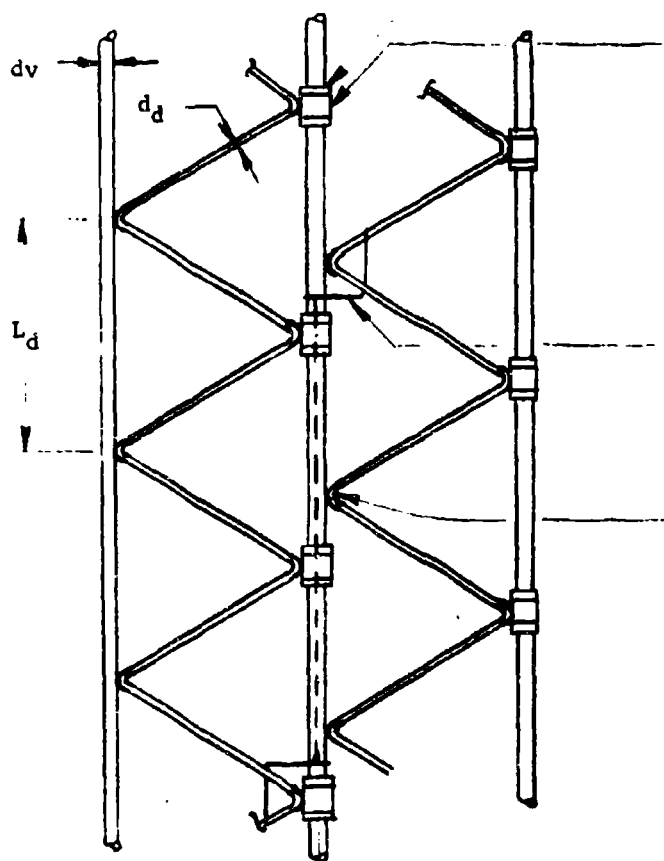
* Modulus of elasticity (E) and end fixity coefficient (C) determined by test described in Section IV



OPENING TORQUE FROM SPRINGS

FLEXIBLE TENSION TIE

SPACER TUBE BONDED TO LONGITUDINAL



HINGE TUBE BONDED TO DIAGONAL

TORSION BAR SPRING

DIAGONAL BONDED TO LONGITUDINAL

TYPICAL MAST SECTION
FIGURE 4

STRUCTURAL PERFORMANCE

There are two specified loading conditions which the mast must meet. First it must stand as a cantilever at a height of 40 feet in a 5 mile per hour wind and second, it must stand at the full height of 100 feet supported by the trees from 40 to 75 feet above the ground with a wind velocity of 10 miles per hour on the upper twenty-five feet. There was no specification requirement for off-vertical erection which can introduce significantly higher loads in the mast. As mentioned previously, additional bending strength has been provided to allow for this effect and some limited analysis has been done.

In both conditions, the total load is a result of the moments applied by the wind load on the mast and the moments applied by the tip mass and weight of the deflected mast. The total moment and deflection is equal to the sum of the individual moments and deflections. The measure of stability of the column is that for an incremental deflection the increase in stored energy due to the stiffness of the column is greater than the increase in applied energy due to the weight of the tip mass and distributed weight of the column. In all cases for this design there is considerable margin of stability so that the structural performance is a function of the bending strength and stiffness of the mast and the applied loads.

Condition I - Forty Foot Cantilever

The applied aerodynamic loads and the resulting shear loads bending moments and deflections due to the drag of the mast in a 10 mile per hour wind are shown in Figure 6. Figure 7 shows the increased root

L	D	d_v	d_d	L_D	I	M	W	D
0	1.5	.080	.055	2.0	.011	78.	.037	.0124
5	1.9	.090	.055	2.0	.023	160.	.045	.0143
10	2.3	.105	.065	2.0	.046	360.	.059	.0167
15	2.7	.130	.065	2.4	.097	725.	.089	.0202
20	3.1	.140	.075	2.6	.147	900.	.097	.0212
25	3.5	.150	.075	2.8	.203	1115.	.119	.0243
30	3.5	.150	.075	2.8	.217	1140.	.120	.0243
40	3.5	.150	.075	2.8	.217	1140.	.120	.0243
50	3.5	.145	.075	2.8	.190	910.	.102	
60	3.3	.130	.065	2.6	.145	744.	.090	
70	3.1	.115	.065	2.3	.100	498.	.068	
80	2.9	.100	.055	2.0	.066	378.	.061	
90	2.7	.085	.055	2.0	.041	234.	.050	
100	2.5	.070	.055	2.0	.024	92.	.043	

L = MAST LENGTH FROM TIP - FEET

d_v = LONGITUDINAL DIAMETER - INCHES

d_d = DIAGONAL DIAMETER - INCHES

L_D = DIAGONAL SPACING - INCHES

I = MOMENT OF INERTIA - INCHES⁴

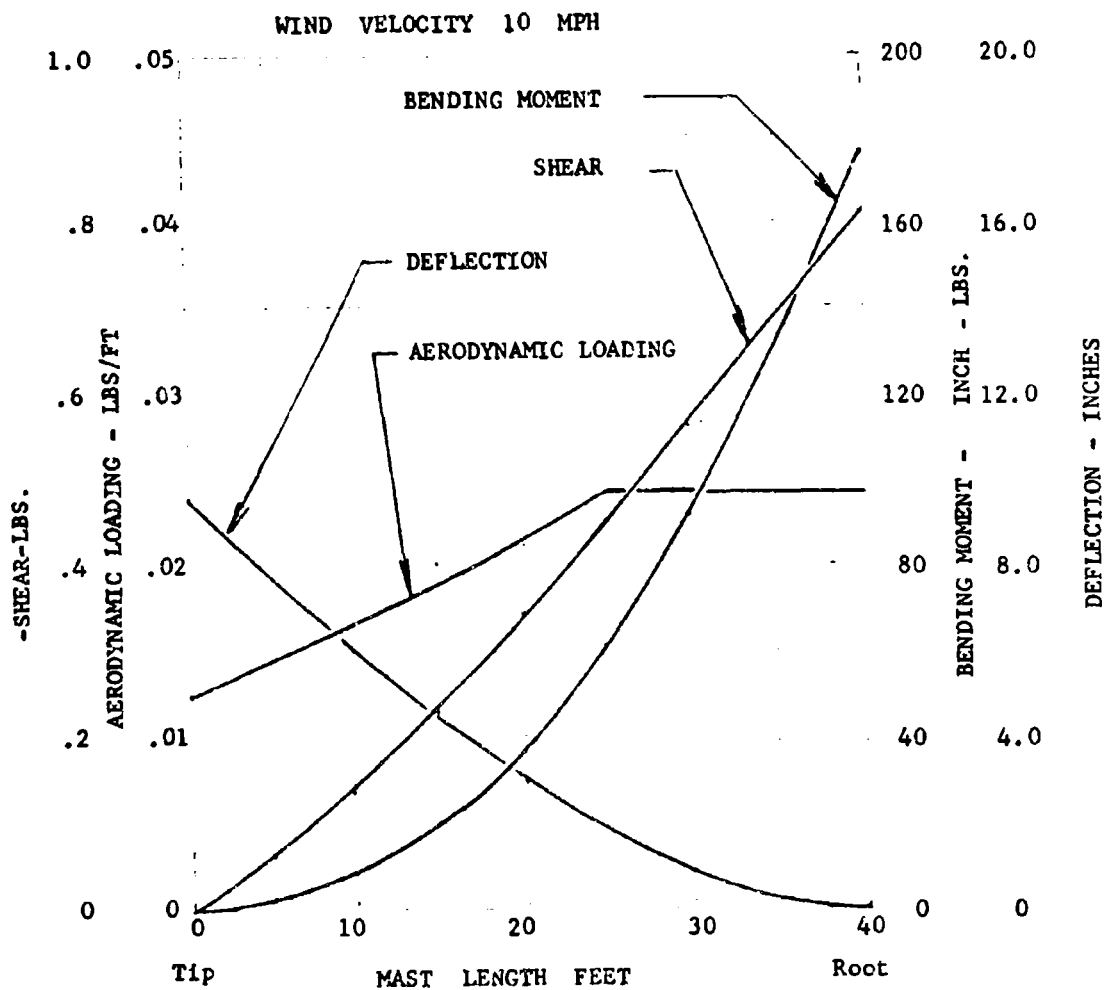
M = MOMENT OF CAPABILITY - INCH POUNDS

W = MAST WEIGHT - POUNDS/FT

D = DRAG AT 10 MPH - POUNDS/FT

MAST CHARACTERISTICS

FIGURE - 5



APPLIED LOADS - 40 FT. CANTILEVER

FIGURE - 6

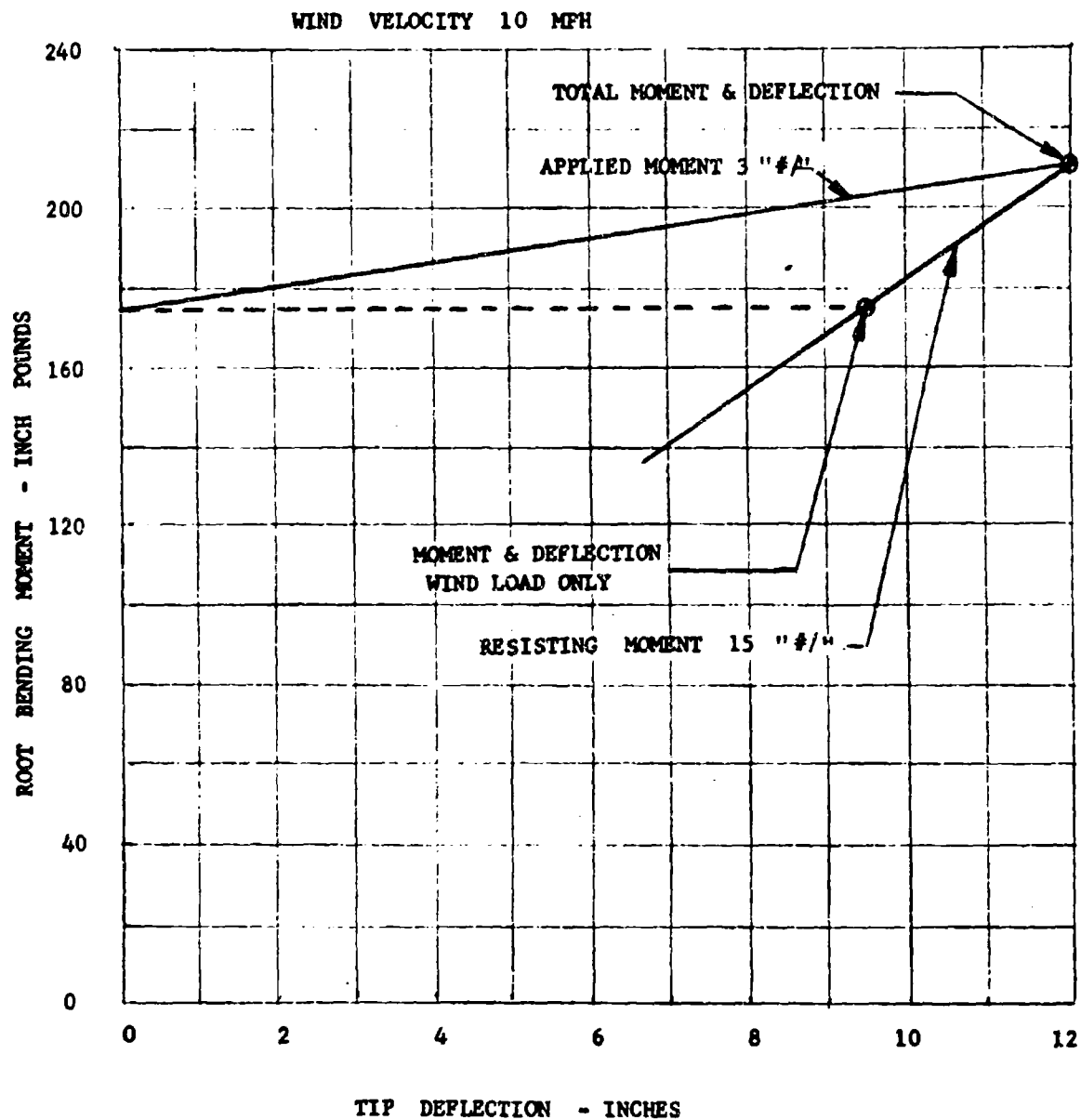
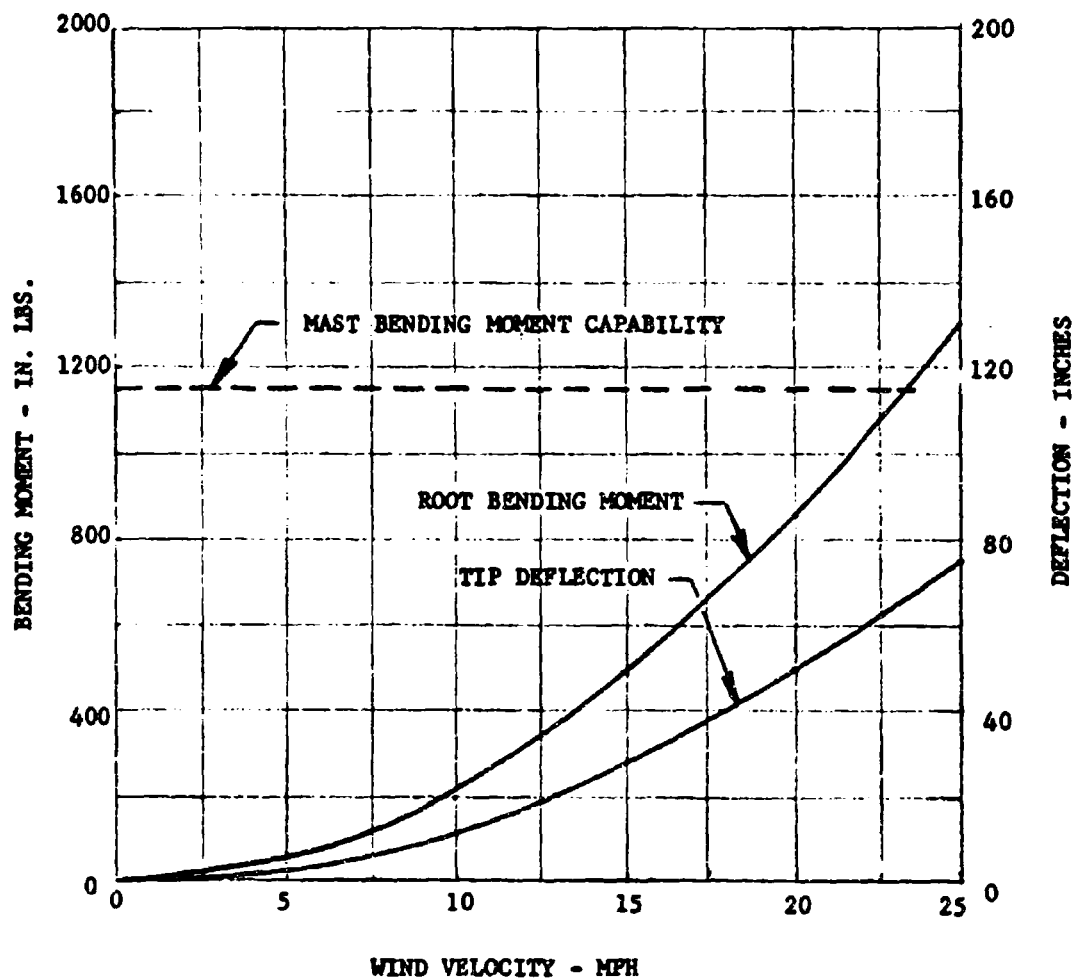


FIGURE - 7

bending moment and tip deflection at 10 miles per hour due to the secondary bending induced by the tip mass and distributed weight of the mast. It is significant to note from this curve that the resisting root bending moment of the mast due to the stiffness characteristics of the mast is 15 inch pounds per inch of tip deflection as it is deflected due to its own weight and the tip mass beyond the deflected position due to the wind loading. At the same time as the deflection increases, the increase in applied load due to its own weight and tip mass is only 3 inch pounds per inch. The column must therefore be stable and the final deflected position is at the intersection of the two curves as shown in Figure 7.

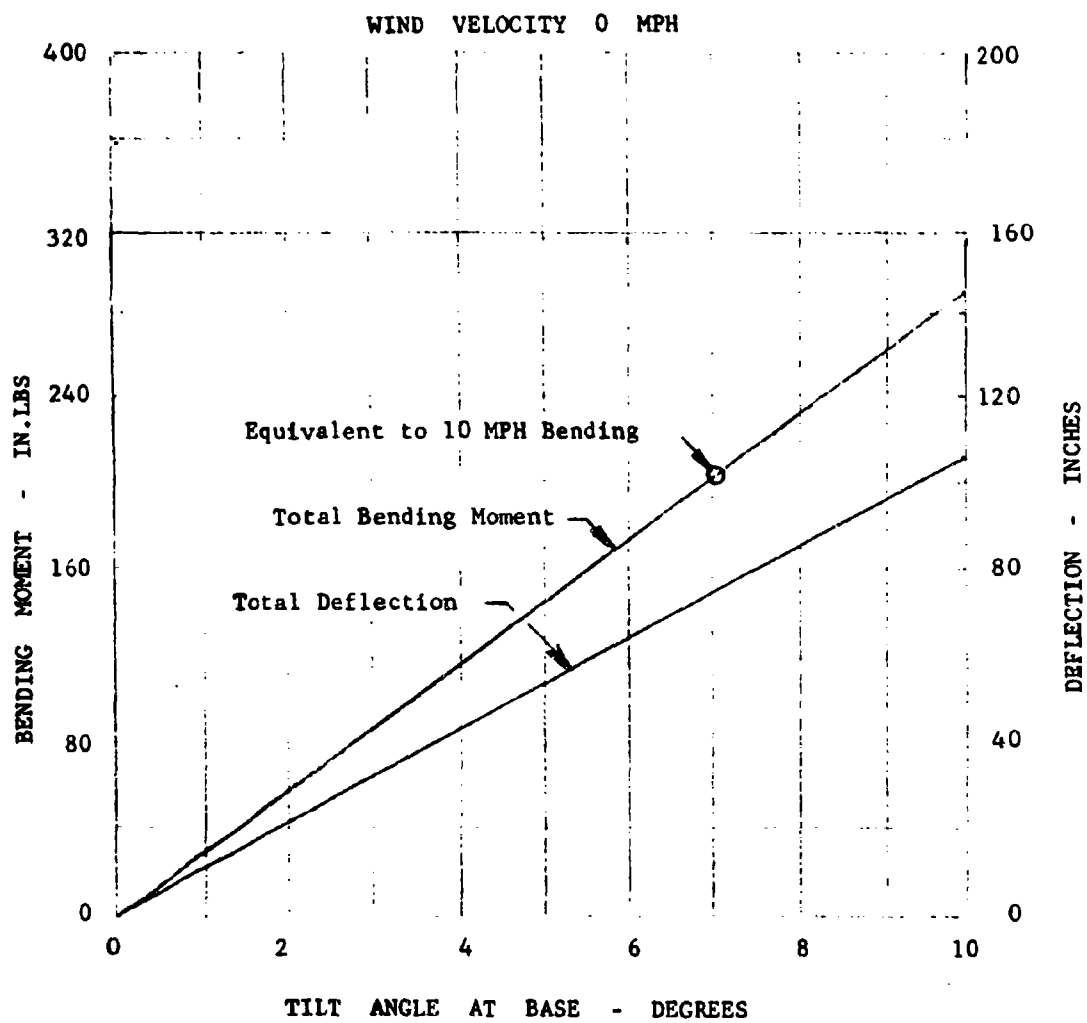
The increase in bending and deflection at any velocity due to this secondary bending will be proportional to the maximum or root bending moment at that velocity. The total bending moment from bending due to the wind load and secondary bending is 20% greater than the moment due only to the wind load while the deflection is 25% greater. Figure 8 shows the total bending moments and deflections as a function of velocity.

The above analysis was performed for the mast deployed to its full cross section. Since the mast is not fully deployed as it leaves the upper support of the storage container, considerably greater deflections will result in some orientations when the mast is a free standing cantilever as demonstrated later in tests. When supported by the man who is erecting the mast, which is the real operating condition, the full stiffness of the deployed section is developed. As a free standing cantilever, the mast has resisted the five mile per hour wind velocity in all directions and has been erected by a man in a 15 to 20 mile per hour wind.



ROOT BENDING MOMENT & TIP DEFLECTION
40 FOOT CANTILEVER

FIGURE - 8



40 FOOT CANTILEVER

FIGURE 9

The effects of off vertical erection are shown in Figure 9. Approximately a 7° tilt of the mast at the base applies a maximum bending movement about equal to that produced by a 10 mile per hour wind.

Condition II - One Hundred Foot Column

The shear loads, bending moments and deflections due to the drag of the upper 25 feet of the mast in a 10 mile per hour wind are shown in Figure 10. Figure 11 shows the increased bending moment at the upper support point (25 ft from tip) and the increased tip deflection, with a 10 mile per hour wind on the upper 25 feet, due to the secondary moments induced by the tip mass and distributed weight of the mast. In this condition the maximum bending and tip deflection are increased by 30% and 35% respectively due to the secondary bending. In this analysis it was considered that the lower 40 feet took no moment which is very nearly true because the stiffness of the lower section is considerably less than the middle section of the mast. The tip deflections and maximum bending moments as a function of wind velocity are shown in Figure 12.

An additional consideration of the beam column is the buckling strength of the lower 40 feet which is unsupported. This is considered as a continuous beam at the upper end where it is supported by the branches and a pin ended column at the lower end. The critical load for this section is 15 pounds as compared to $9\frac{1}{2}$ pounds which is the weight of the mast and the tip mass.

In all of the above analysis the direct compressive loads in the longitudinals due to the tip mass and mast weight has been neglected. In the top 50 feet of the mast where the bending moments are high, this

WIND VELOCITY 10 MPH

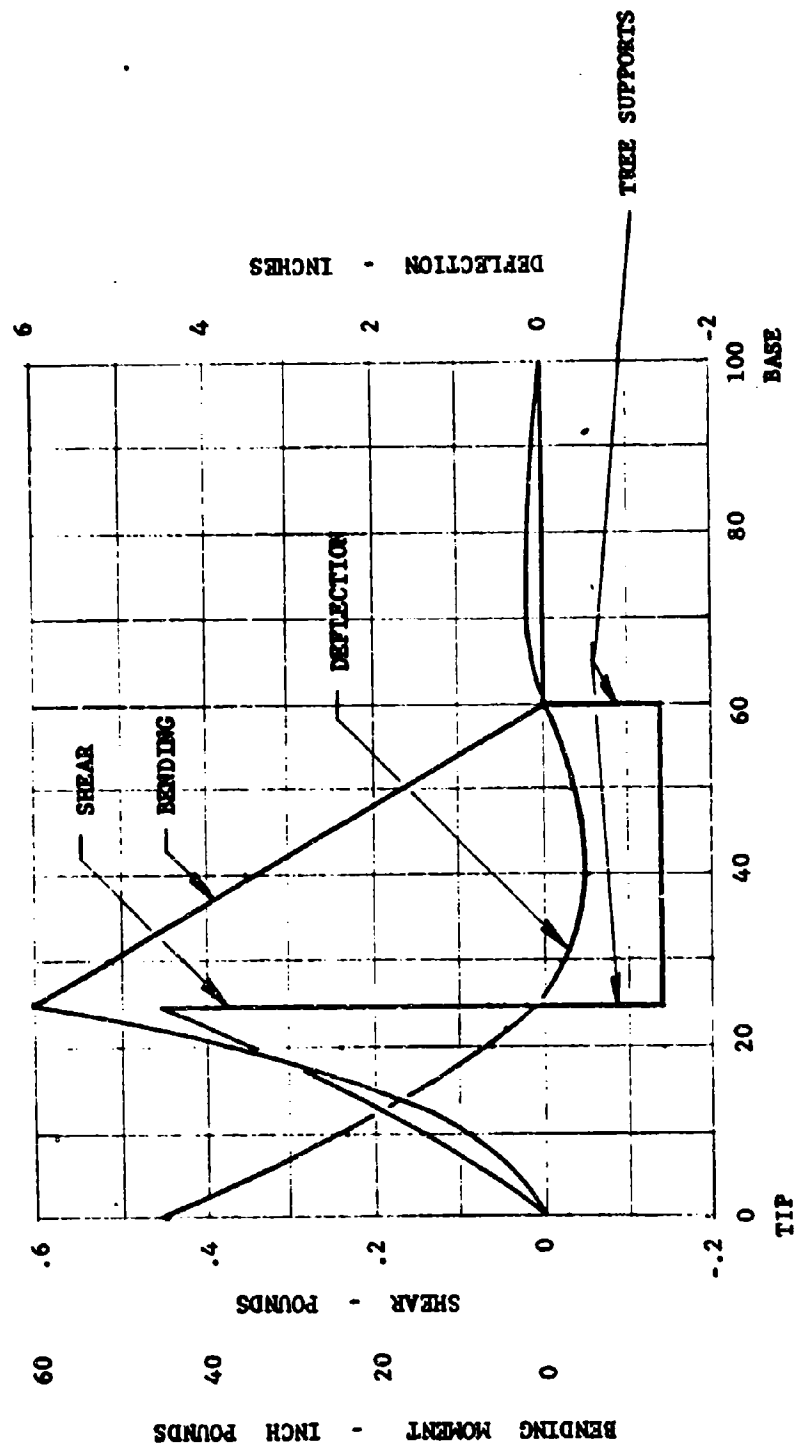


FIGURE - 10

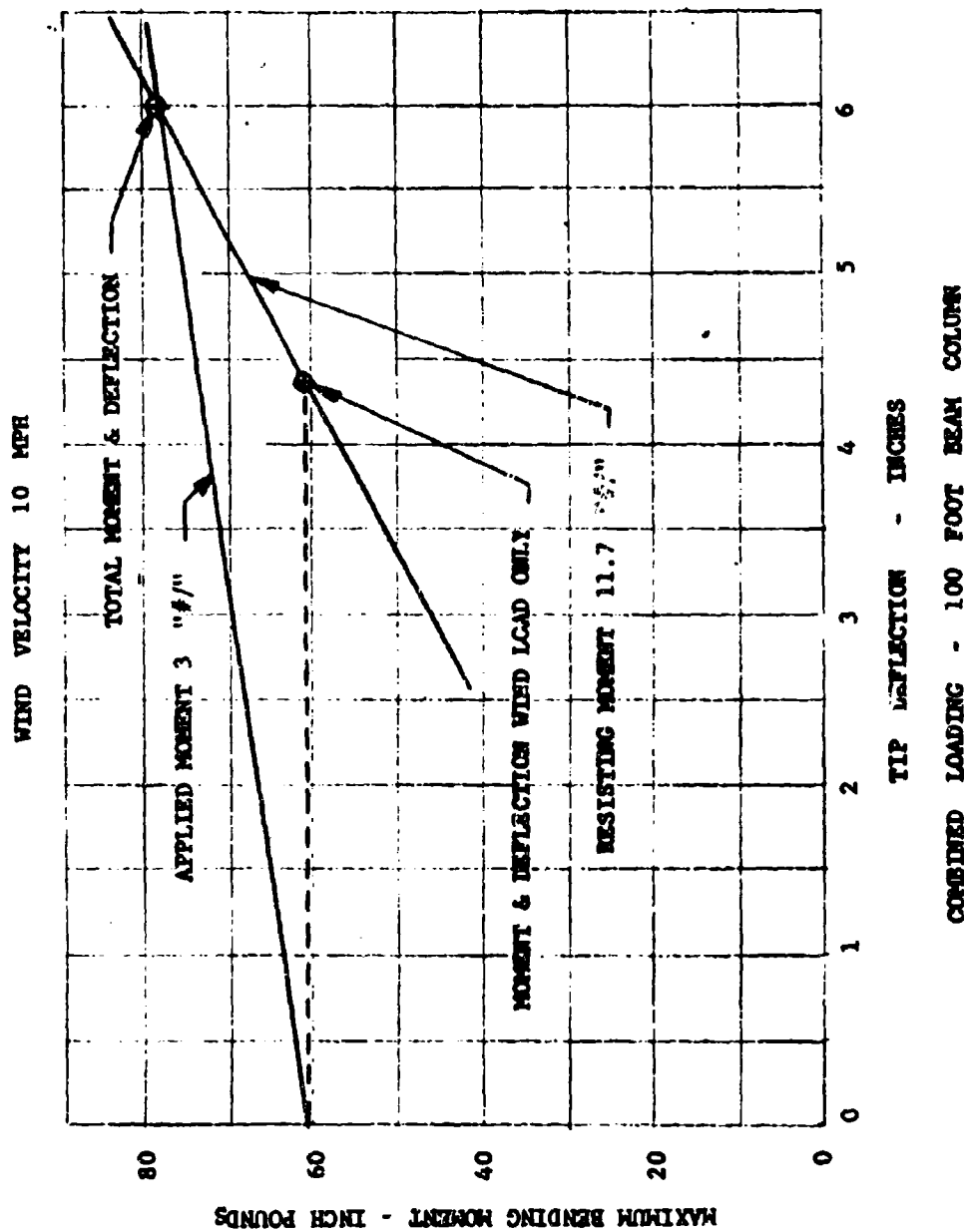
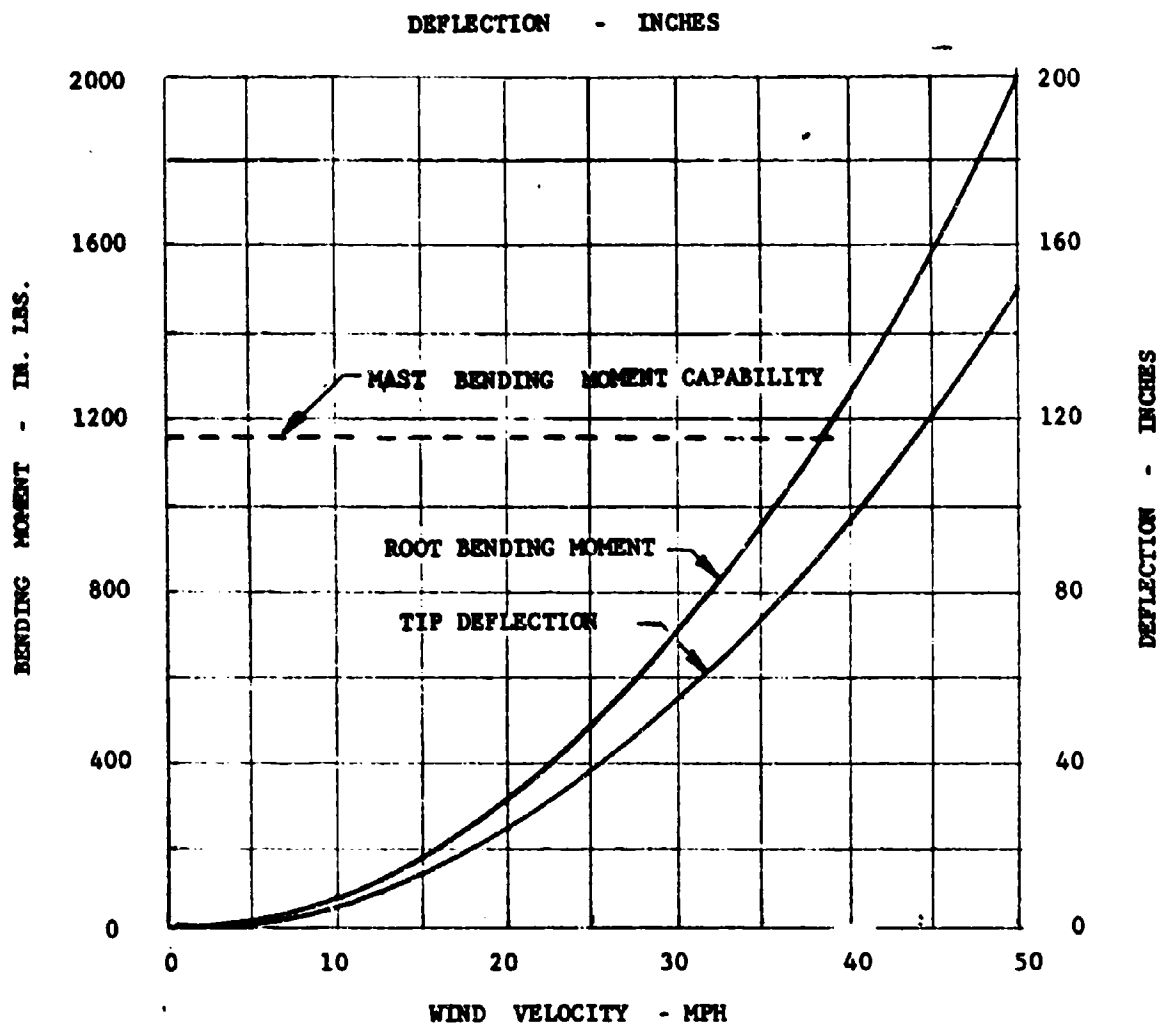


FIGURE - 11



MAXIMUM BENDING MOMENT & TIP DEFLECTION
100 FOOT BEAM COLUMN

FIGURE - 12

adds less than 100 pounds per square inch compressive stress or less than 1% of the buckling stress. In the lower section where the bending moments are low, the compressive stress is less than 1000 pounds per square inch.

STORAGE REEL DESIGN

The purpose of the storage reel is to provide a mechanism whereby the one hundred feet of mast can be stored conveniently in a small package. It must provide a means to control the stored energy of the mast as it is deployed or retracted. It should also provide protection for the mast during transportation and for normal handling loads. The storage reel is shown in Figures 13, 14 and 15.

To achieve a minimum package size, it is desirable to wrap the mast on the smallest diameter reel which will not overstress the mast. The bending stress in this type of mast is the stress developed by coiling the longitudinal elements and follows the relationship

$$S = \frac{E d_v}{d_r} = \frac{dv}{dr}$$

where

d_r = diameter of reel

d_v = diameter of longitudinal

E = bending modulus of elasticity

Early testing indicated that the bending stress at which a fiberglass rod would rupture was considerably reduced when going from room temperature to the elevated storage temperatures of 155°F. Whereas the epoxy fiberglass rods using a TETA accelerator had an allowable bending stress of 125,000 to 150,000 PSI at room temperatures, this reduced to

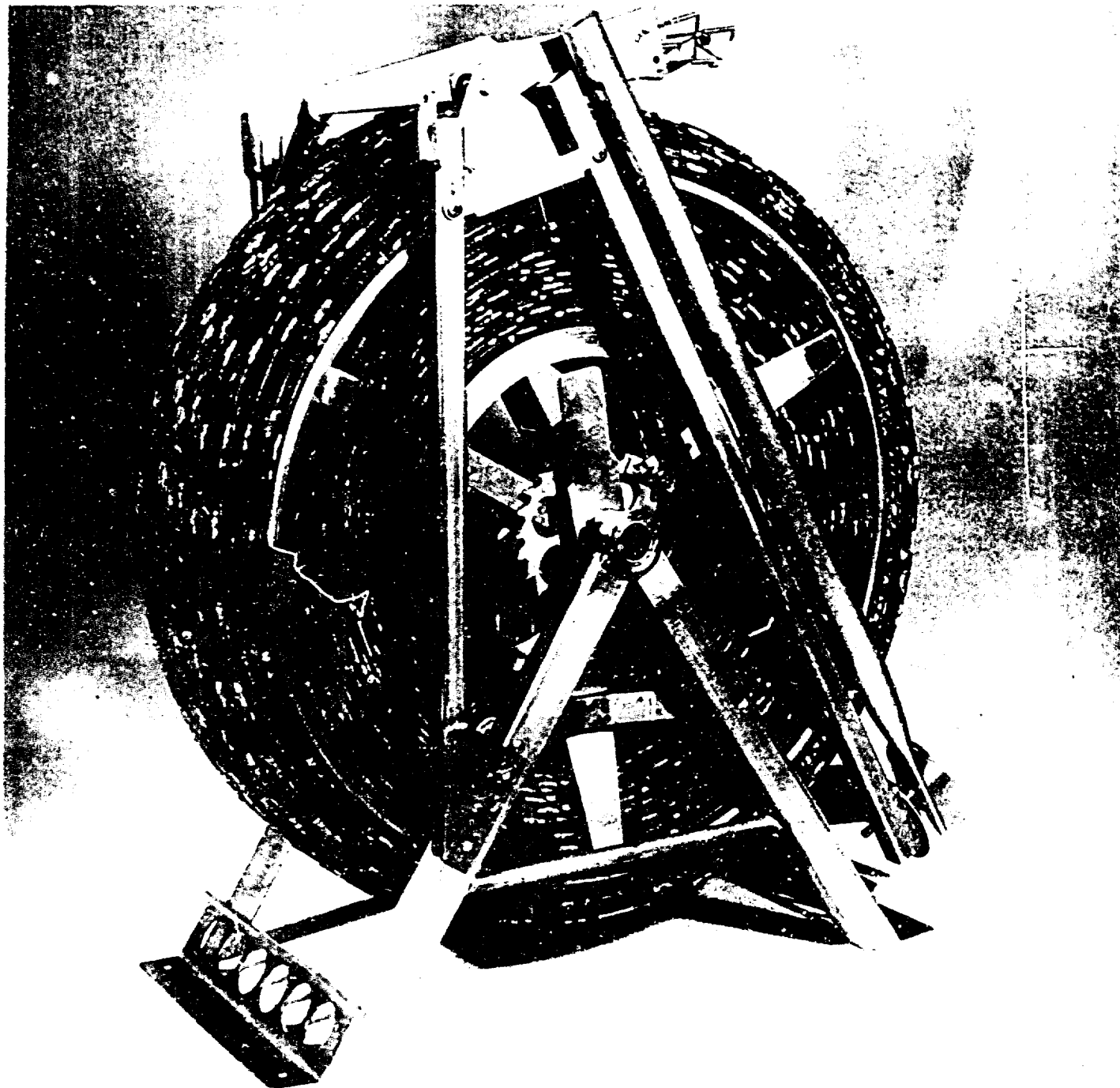


FIGURE 13 - MAST AND STORAGE REEL - STOWED

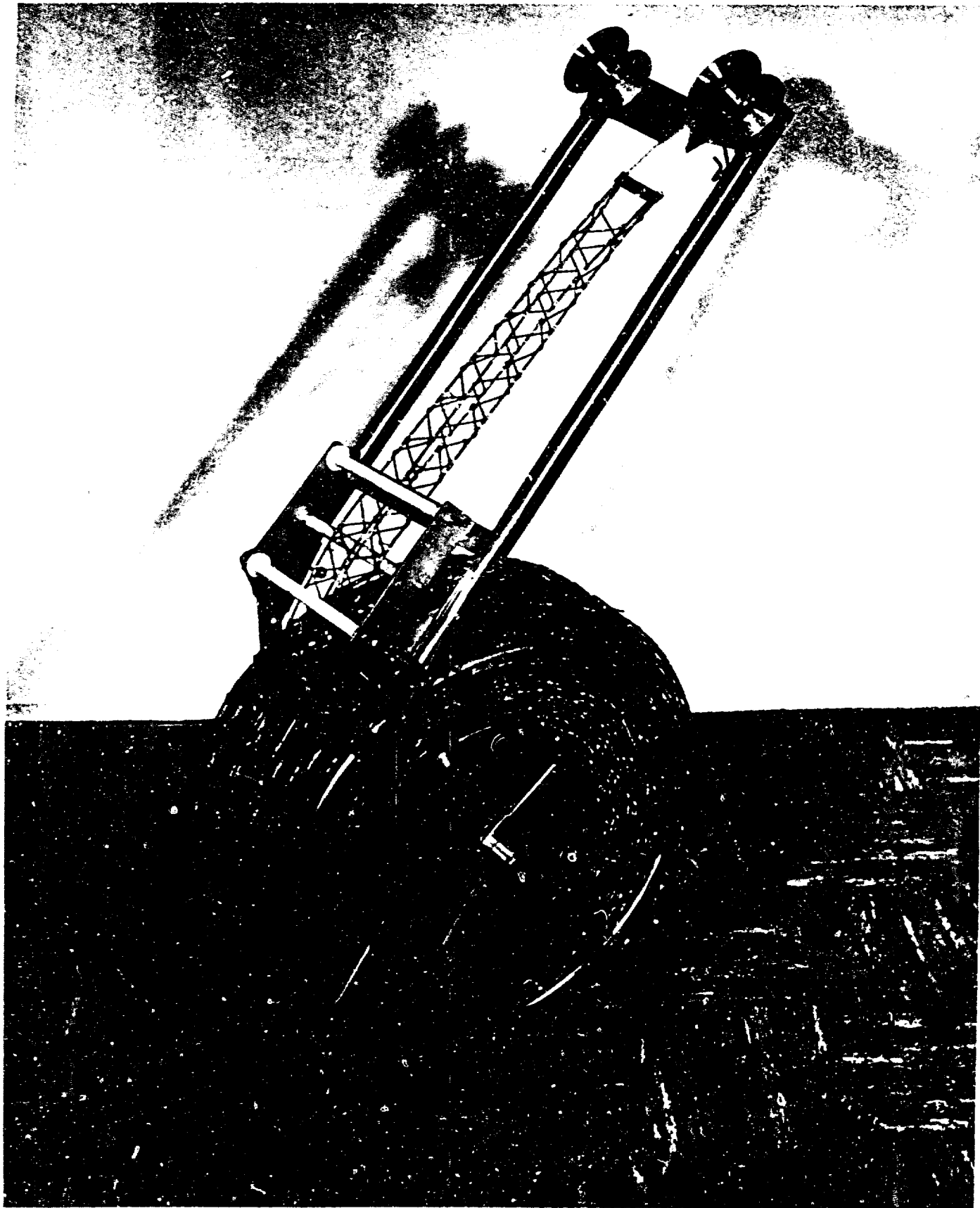


FIGURE 14 - MAST AND STORAGE REEL - PARTIALLY EXTENDED

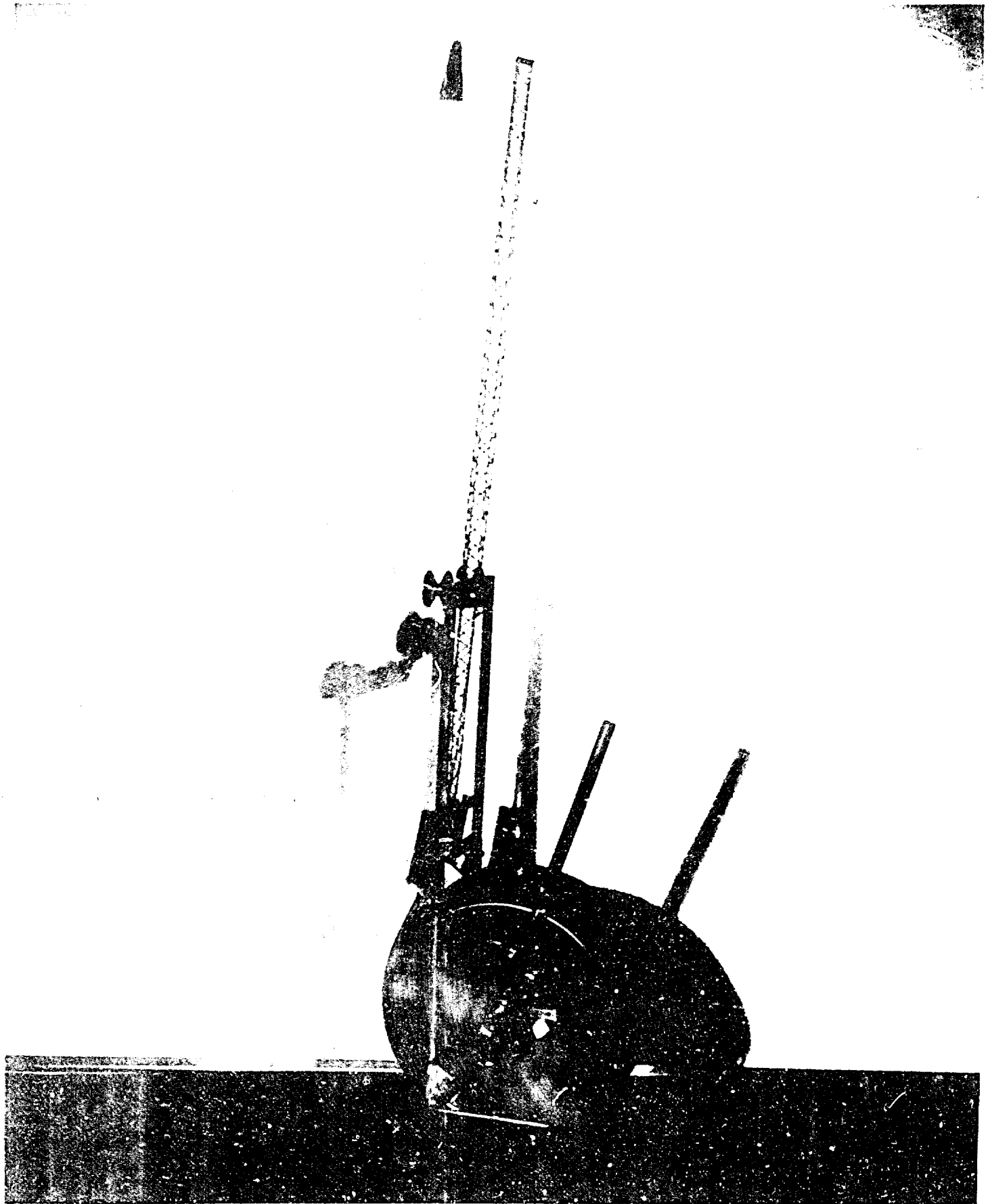


FIGURE 15 - MAST AND STORAGE REEL - OPERATING POSITION

about 75,000 PSI at 155⁰F. As a result, utilizing the previous stress relationship, the coil diameter of the longitudinals was maintained at a minimum of 100 times the cross sectional diameter of the longitudinal.

Tapering of the longitudinal diameter toward the base of the mast increases the packaging efficiency in that a smaller reel diameter can be used and less thickness per layer is required. As the mast is rolled up on the reel, the diameter of the longitudinals is increasing as the coiled diameter increases due to the increased layers on the reel. The coiled stress is maintained at a nearly constant value from the base of the mast to the maximum cross sectional diameter of the longitudinals. The increase in radius of the coil for each layer comes out to be very closely equal to the longitudinal diameter plus twice the diagonal diameter. For this design, the reel diameter was chosen at 8.0 inches with a resulting maximum diameter of the total 100 feet on the reel of 22 inches.

Another important feature of the storage reel design is the energy in the coiled mast which acts much like a clock spring. The bending moment in the coiled mast is expressed by the relationship

$$M = S I/C$$

where I/C is the section modulus of the flat tape. For this type of structure, all of the coiled stiffness is provided by the four longitudinals and none by the diagonals.

$$I = 4 I_v = \frac{4 \times \pi d_v^4}{64} = \frac{\pi d_v^4}{16}$$

$$c = d_v/2$$

$$S = \frac{d_v}{d_r} E$$

$$M = S I / c$$

$$M = \frac{\pi E d^4}{8 d r}$$

Since the moment on the reel varies as the fourth power of the diameter of the longitudinal, the maximum moment will be where the maximum diameter of the longitudinal is coiled on the smallest radius. For this design these values are .150" diameter of longitudinal at approximately 15" coil diameter giving a torque of approximately 65" inch pounds in the coil.

Because of the stored energy in the coiled mast, the coil always wants to grow to the largest diameter possible to relieve the stored energy. This can cause either the storage reel to unwind or the exit end of the mast to wind back on the coil. To provide a design in which the mast will wind tightly on the reel and to prevent sliding of coiled layers, both these effects must be reacted. In this design a friction brake on the reel was selected to resist the unwinding torque on the reel. Other methods such as a negator spring were considered. The negator spring counteracting the torque in the mast would require less torque on the handle to retract the mast, but the weight of the spring to develop the torque for the total number of revolutions of the storage reel is prohibitively large. As the mast exits from the storage reel it is fed through three rollers which apply pressure to the mast to keep it from winding back on the reel.

The minimum torque required on the drive handle is the sum of the moment applied by the coiled mast and the friction of the brake. In this design, this is a minimum of 130 inch pounds since the brake friction must be set to be at least equal to the moments of the coiled mast.

SECTION III

MANUFACTURE

The mast is manufactured from fiberglass rods for the complete length except for the torsion bar springs required to spring the mast to its rectangular cross section. These springs are made from stainless steel spring wires.

All fiberglass rods for the mast have been furnished by Columbia Products, Columbia, S.C. Columbia Products was selected because of the high modulus of elasticity achieved by their manufacturing process and because of the ability to form the uncured rods in to the desired diagonal shape.

The process used by Columbia Products winds four layers of cellophane tape around the impregnated fiberglass roving. Two layers are wound clockwise and two layers are wound counterclockwise as the rod is being drawn. This tape wrapping forms and holds the circular cross section of the rod until it is cured. It also assures a high fiberglass content which is the main factor in achieving a high modulus of elasticity of the cured rod. The glass content of these rods is 85% and the modulus of elasticity is 5,000,000 to 6,000,000 P.S.I. The cellophane tape is stripped by a high pressure water jet after the rods are cured. There remains, however, a spiral impression of the tape around the circumference of the cured rod which is characteristic of the tape wrapping process.

The longitudinal elements are round fiberglass rods whose diameter is tapered along the length. They are furnished in ten foot lengths and spliced with tubular aluminum sleeves during the assembly process. The binder for the fiberglass roving was epoxy with TETA accelerator for the first mast and epoxy with anhydride accelerator for the second mast. The anhydride material has better high temperature characteristics which is required to allow the mast to be coiled on a small diameter reel and withstand the high temperature storage environment.

The diagonal elements are furnished in the tape wrapped but uncured state so that they may be formed to the proper shape before curing. To allow shipping and storage without curing a polyester binder was selected. However, it is also possible that the anhydride epoxy which is now available could also be used for the diagonal elements since it has a slow curing process at room temperatures.

The basic materials, in addition to the tapered longitudinal rods, for fabrication of the mast are shown in Figure 16. To form the diagonal members, the uncured fiberglass rod is laid up on the pin fixture as shown in Figure 17. The member is cured at 190° for four hours and then removed from the fixture. The cellophane tape is then removed from the cured diagonal by a high pressure water jet.

The tubular hinge joints are then fastened to the diagonals as shown in Figure 17. The hinges are first bonded to the diagonal. The joints are then wrapped with fiberglass tape and finally impregnated with epoxy. Curing of the bonds is accomplished under infra-red heat lamps. The excess fiberglass tape between the hinge joints is then trimmed away.

The assembly of the complete mast is accomplished on a long assembly bench as shown in Figure 18. The hinge joints on the diagonals are slid on the longitudinal rods along with two end sleeves between each hinge. All four truss panels are laid out flat with locating strips and pins on the bench to position the longitudinals and hinges in their correct spacing. The ends of the diagonals opposite the hinge joints are bonded to the longitudinal rods, wrapped with fiberglass tape and epoxy impregnated. The end sleeves are slid tight against the hinges and bonded in place. Joints are made in the longitudinals by a telescoping aluminum sleeve bonded in place. Joints are staggered so that no two fall at the same place. As the flat assembly proceeds from the mast tip to root, the completed section is rolled up in a drum at the end of the table.

After the entire length is completed as a flat panel, section is folded in half in the same manner that it will be when rolled on the storage reel. In this position the final row of joints of diagonal to longitudinal are made. The final assembly operation is to install the torsion bar springs and the flexible cross ties.

Using the above assembly procedure, both masts assembled had excellent straightness. The only minor problem occurs where the sections change from a tapered section to non-tapered. Here one side of the mast remains straight while all the taper occurs in the other side. The maximum deviation from true straightness was measured at 3 inches over the entire 100 foot length of the second mast.

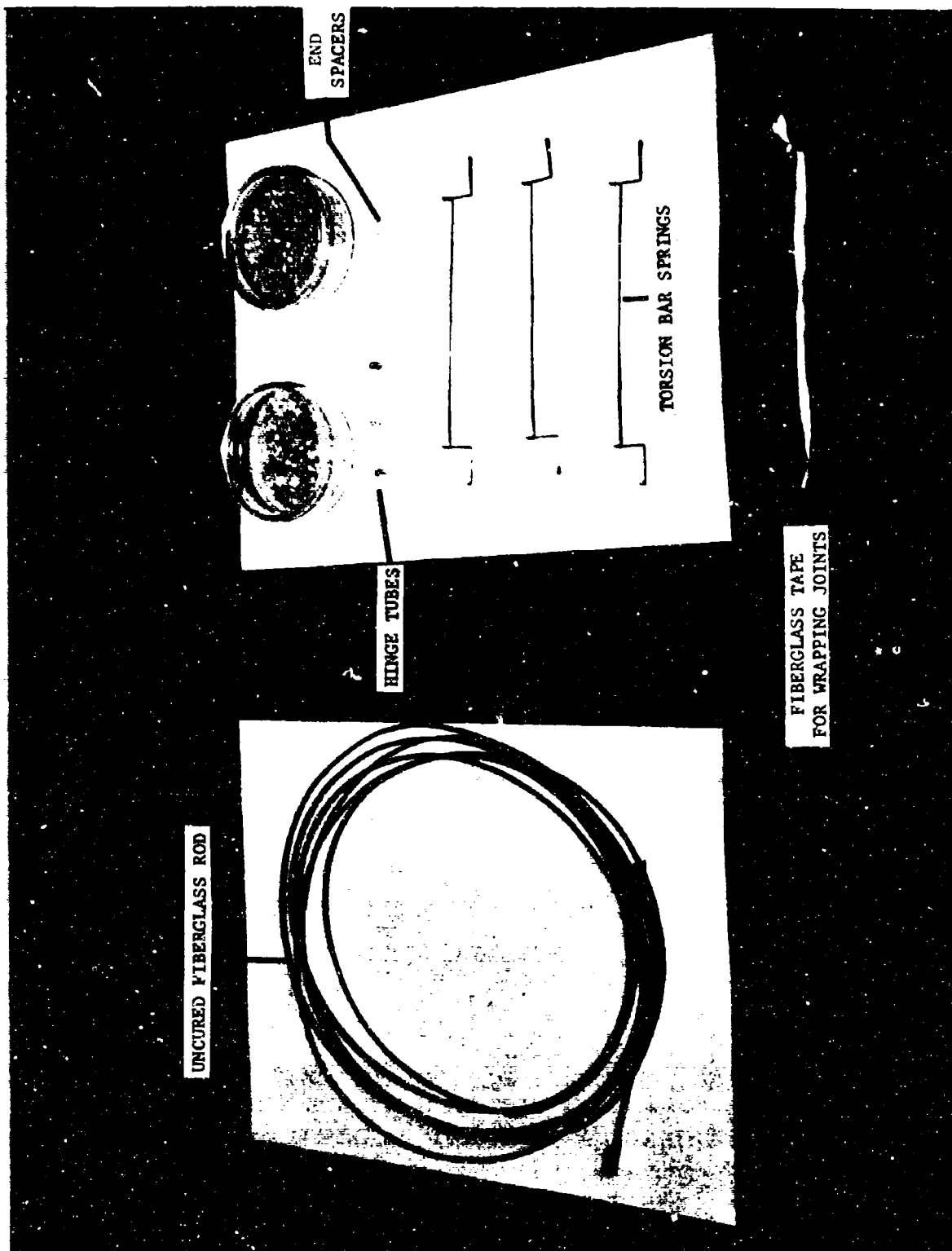


FIGURE 16 - MAST MATERIALS

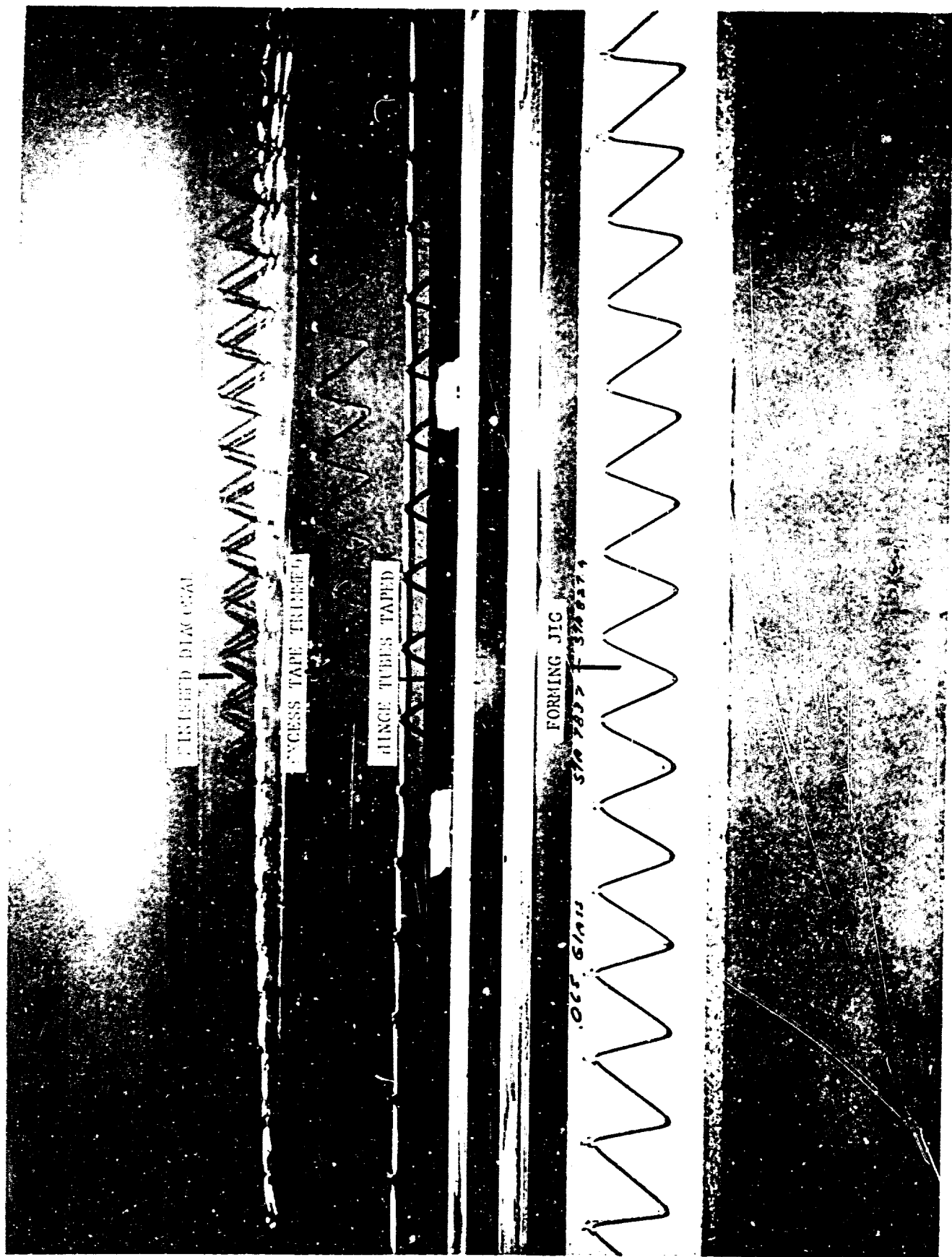


FIGURE 17 - DIAGONAL FIXTURES

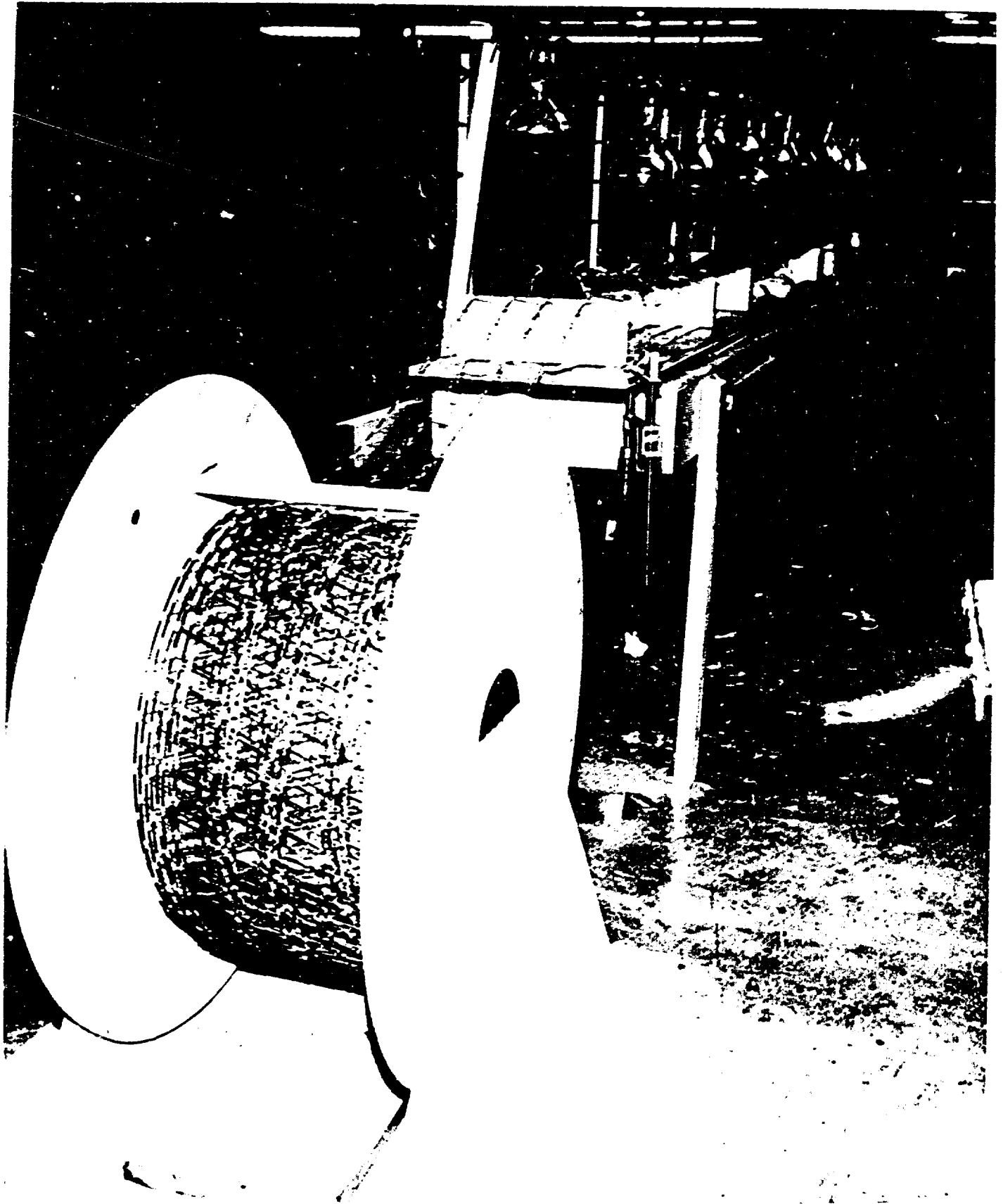


FIGURE 18 - ASSEMBLY BENCH

SECTION IV

TESTING

DEVELOPMENT TESTING

A bending test was run to determine the load-deflection characteristics of a square mast sample. The set-up is shown in Figure 19 and the dimensions of the sample and deflection characteristics are shown in Figure 20. The effective modulus of elasticity was from 4,850,000 to 5,370,000 PSI and the maximum bending strength in the weakest direction was 35 foot pounds.

An aerodynamic drag test was run on both the round and square masts utilizing the fixture shown in Figure 21. The fixture was mounted on a vehicle which was driven at varying velocities up to 45 MPH. The data is shown in Figures 23 and 26. Analysis of the data indicates a drag coefficient of 0.8 for both the round and square masts based on the total projected area of all the elements.

A storage temperature test of a spliced longitudinal rod was run. A .110 diameter rod stored on a 5 inch radius drum at 155°F for seven days. The curvature of the rod after the test was approximately a three foot radius. A similar test is being run on a .187 diameter rod that has been post cured at 400°F to give improved high temperature performance. The set due to storage temperature should not affect the straightness of the deployed mast, but does affect the energy required to deploy it from the flat to the square shape and therefore should be kept to a minimum.

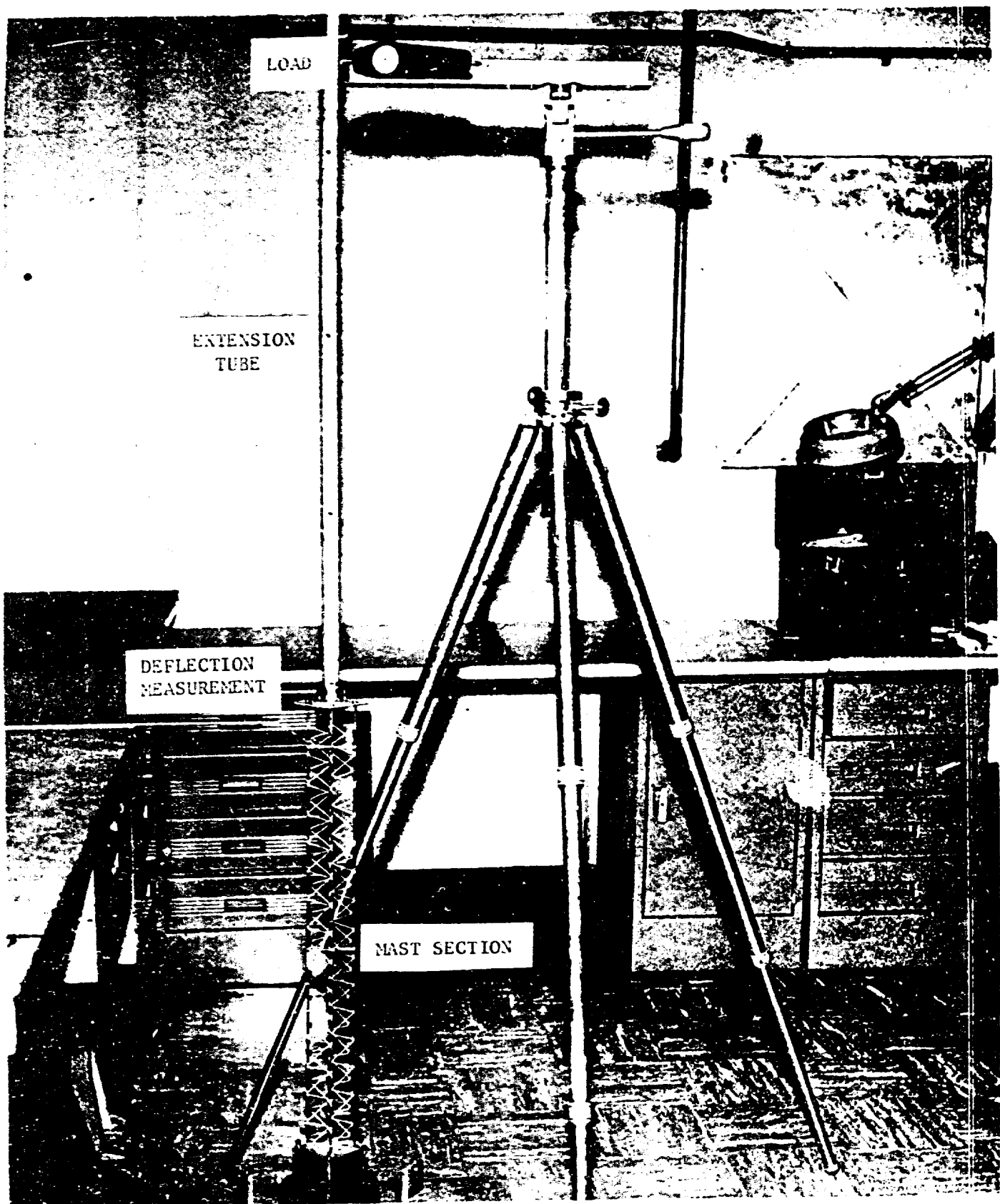


FIGURE 19

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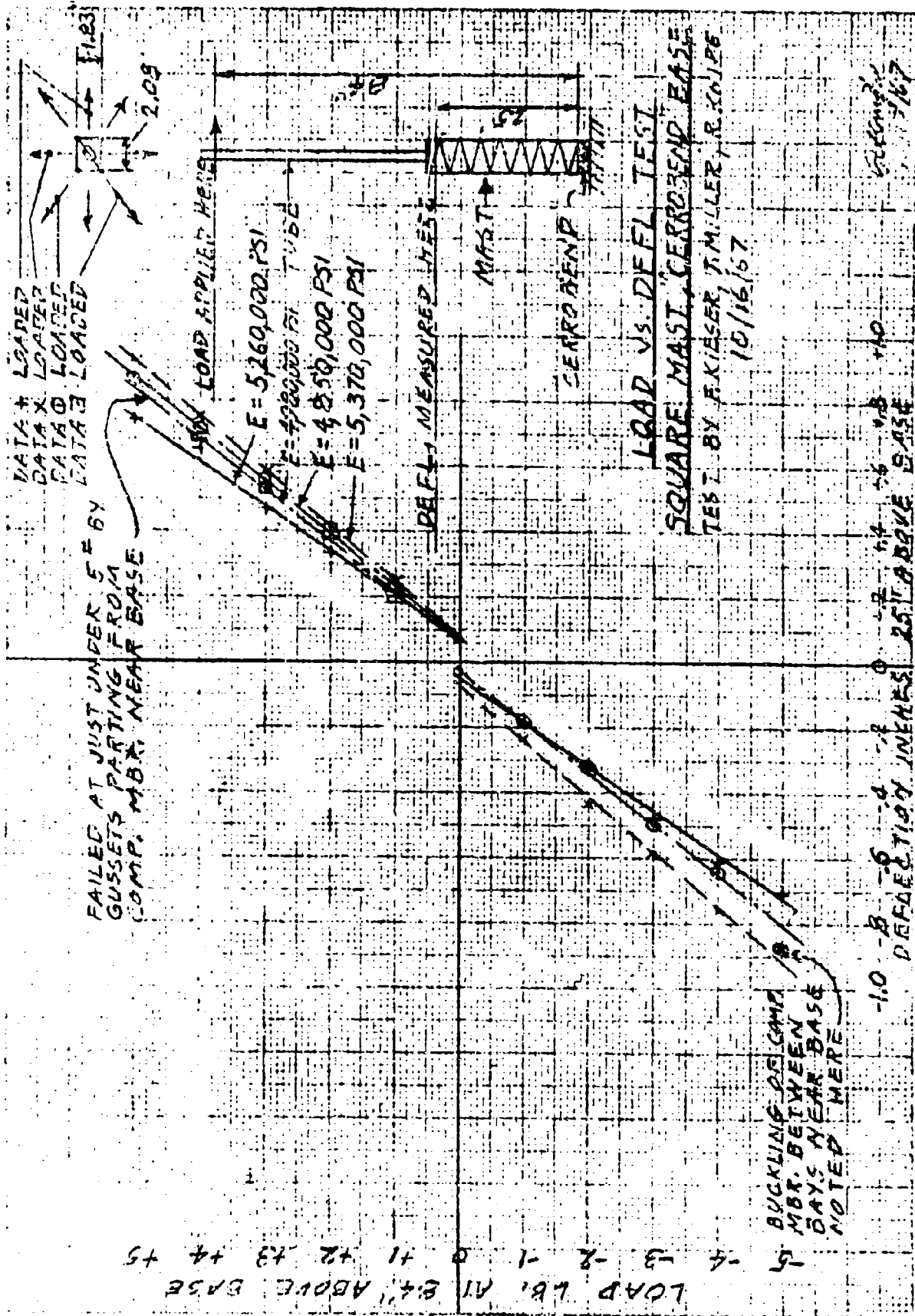


FIGURE 20

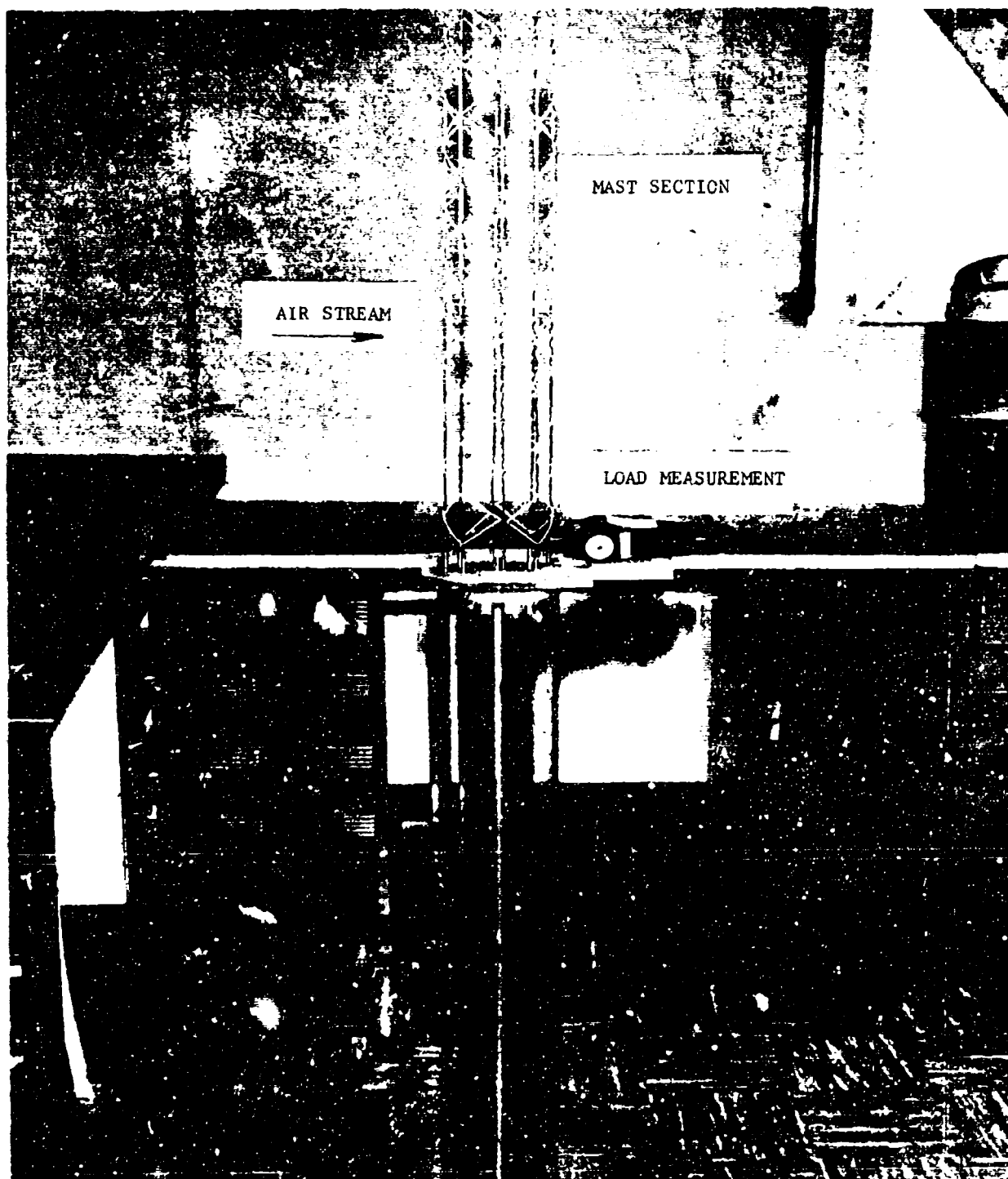
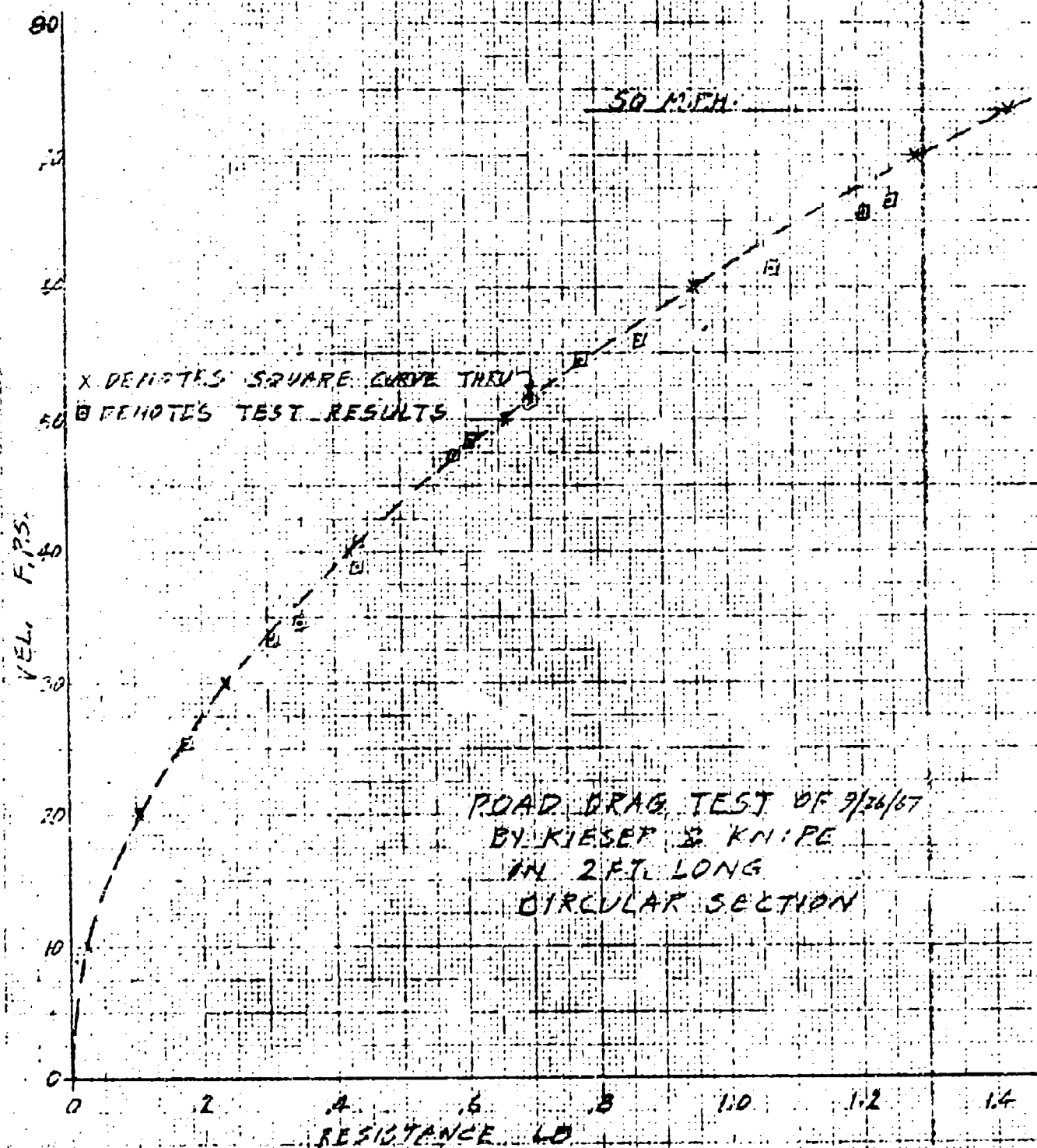


FIGURE 2.1

NOT REPRODUCIBLE



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FIGURE 7

EVALUATION TESTING

Summary

The antenna mast was subjected to the following tests:

1. Structural Loading Tests
2. Storage Temperature Tests
3. Operational Cycling Through Trees
4. Fifty Mile Per Hour Wind Survival

The results of these tests indicate that the mast exceeds the specification requirements for structural strength having been tested in winds of 20 miles per hour at the full 100 foot height with a specification requirement of 10 miles per hour. It is believed that this is a significant advantage because at no time was the testing delayed due to wind conditions even though the winds were higher than 10 miles per hour during much of the testing.

Some minor design deficiencies were uncovered and corrected as described later.

The problem uncovered during this testing which will bear continued observation with further use is the wear problem on the truss joints. Several design changes are possible to eliminate this problem but could not be implemented on these two masts. Further effort should be expended in this area.

The problem of snagging of limbs in the truss which earlier had appeared as a problem did not appear in this testing principally due to design changes between the first and second masts. Again, this will bear continued observation with further use since these tests were conducted in the local environment which may not be totally representative of effects

produced by the jungle trees. It is the opinion of the writer that the jungle trees will not pose a problem.

In the fifty mile per hour wind survival test, the mast was collapsed over tree limbs and was smoothly retracted without damage, sliding over the tree limb, to a point where it redeployed to its full section at which point it could be retracted in its normal fashion or re-erected.

Description and Results

Testing of the complete antenna mast assembly was begun on August 22, 1968, with Mr. A. Sigismondi of the U. S. Army Electronics Command in attendance. F. Kieser and S. Rubenstein of SSO conducted the tests.

The following tests were conducted on August 22:

1. Deflection test of 40 ft. cantilever cantilever column.
2. Erection of 40 ft. cantilever column with $1\frac{1}{2}$ pound tip mass in 5 mph wind.
3. Erection of full 100 ft. mast with $1\frac{1}{2}$ pound tip mass through trees. During this test recovery of the mast after being collapsed over limbs was demonstrated twice.

The first test was conducted in the laboratory while the second and third tests were conducted outside with a wind velocity of approximately 5 to 10 miles per hour. The tests were successfully accomplished with no damage to the mast.

The forty foot cantilever test was conducted with a test set up

and deflections as shown in Figure 24. The deflections, when loaded in the plane of flattening of the mast, were as predicted. The loading in this condition was run to an equivalent wind velocity of 8 mph with no indication of failure. The high deflections in the planes not in the direction of flattening were much higher due to flexure of the mast in the transition from the square to flat section. Loads in this condition equivalent to 5 miles per hour wind velocity were applied with no failure. No tip load was used in this test but the capability of meeting specification with the tip load was demonstrated in the succeeding outdoor test.

In the second test, the mast with the $1\frac{1}{2}$ pound tip mass was erected as a forty foot cantilever in a 5 to 10 miles per hour wind. The erected mast appeared extremely stable even when not exactly vertical.

In the third test, the mast with the $1\frac{1}{2}$ pound tip mass was erected through a tree. The first limb support was at about 25 feet. When the mast was erected to approximately 40 feet, the tip struck a large limb and the resulting deflection collapsed the mast over one of the lower limbs. The collapsed mast bent a full 180 degrees over the limb so that the tip mass was approximately 3 to 4 feet below the supporting limb. Cranking the mast down at the base pulled the tip mass up over the supporting limb. The same condition occurred a second time over the next lower limb. This time when the mast was lowered to pull the tip over the limb, the mast opened to its full section and the vertical erection of the mast was resumed. The mast was then erected to its full one hundred feet with more than 25 feet extending above the uppermost tree support. The mast was inspected as it was reeled in. There appeared to be some minor abrasion marks on the fiberglass where it was pulled over the limbs but there was no breaking of any of the members from

This test.

Storage temperature test was conducted by placing the mast assembly in an oven at 155⁰F for four hours. The mast was then removed and deployed. No change in characteristics were noted.

One hundred operational cycles through trees were performed between August 31 and September 10 in wind conditions up to at least 20 miles per hour. The attached photographs show the tree conditions for this testing. The mast was examined at every ten cycles for integrity of the joints and the diagonal fiberglass truss members. Table I shows the conditions observed and corrective action taken.

After the operational cycle test was complete, the mast was removed from the reel and closely examined. Some of the non-rotating joints at the center of the flat mast section were worn to a greater or lesser degree particularly in the area of 25 to 50 foot elevation. Approximately thirty joints (out of a total of 2400) were judged to be worn to a point where it was desirable to retape the joints and this was done. One diagonal member at the 20 foot elevation was partially fractured and this was repaired.

TABLE I

<u>Date</u>	<u>Cycles</u>	<u>Observations</u>	<u>Corrective Action</u>
Aug 31	12	---	---
Sept 1	15	1. 2 non-rotating joints loose at 25 ft elevation. 2. Drum Torque increased. 3. Ratchet weld to collar failed.	1. Joints taped in place with pressure sensitive strapping tape. 2. Brake cleaned and re-adjusted. Second brake disc hard anodized. 3. Rewelded with increased weld strength.
Sept 5	15	1. 1 rotating joint loose 25 30 ft. elevation. 2. 1 non-rotating joint loose at 35 ft. elevation. 3. Ratchet slipping intermittently.	1. Joint taped . 2. Joint taped. 3. Ratchet link replaced with longer link.
Sept 7	26	1. 2 non-rotating joints loose. 2. 1 rotating joint loose	1. Joint taped 2. Joint taped and guide rollers removed.
Sept 8	20	---	---
Sept 10	12	---	---

Of the problems noted in Table I, the ratchet weld failure and the ratchet slipping have been corrected by design changes which have been implemented on both storage drum assemblies and no further problem is expected.

The increased drum torque was due to roughening of the aluminum brake disc. The brake disc on the second storage drum was hard anodized and it is

felt that this should correct the problem, although it has not been cycled to verify this change.

The joint wear problem is being caused by roller system through which the mast is fed to facilitate erection and retraction and to hold the mast as a cantilever. Further consideration should be given to elimination of these rollers particularly the upper rollers that hold the mast as a cantilever since the mast is to be used with support from the trees. As shown in Table I, these rollers were removed for the last 32 cycles with no apparent detriment to the ease of operation. Several potential methods of solving the wear problem are being considered and will be discussed in a later report. It should be noted that the mast was operated in wind conditions much in excess of the specification and at no time was there any problem with structural integrity of the mast. Also repair of wear areas can be accomplished easily.

No problem of snagging in the tree limbs was encountered in these tests. The mast erected and retracted smoothly through the trees. On at least one occasion, the mast was left erected for a period of one-half hour in a 20 to 25 mile per hour wind that caused considerable sway to both the tree and the mast. It was anticipated that a condition such as this would encourage working of limbs or leaves into the mast truss, but no problem resulted.

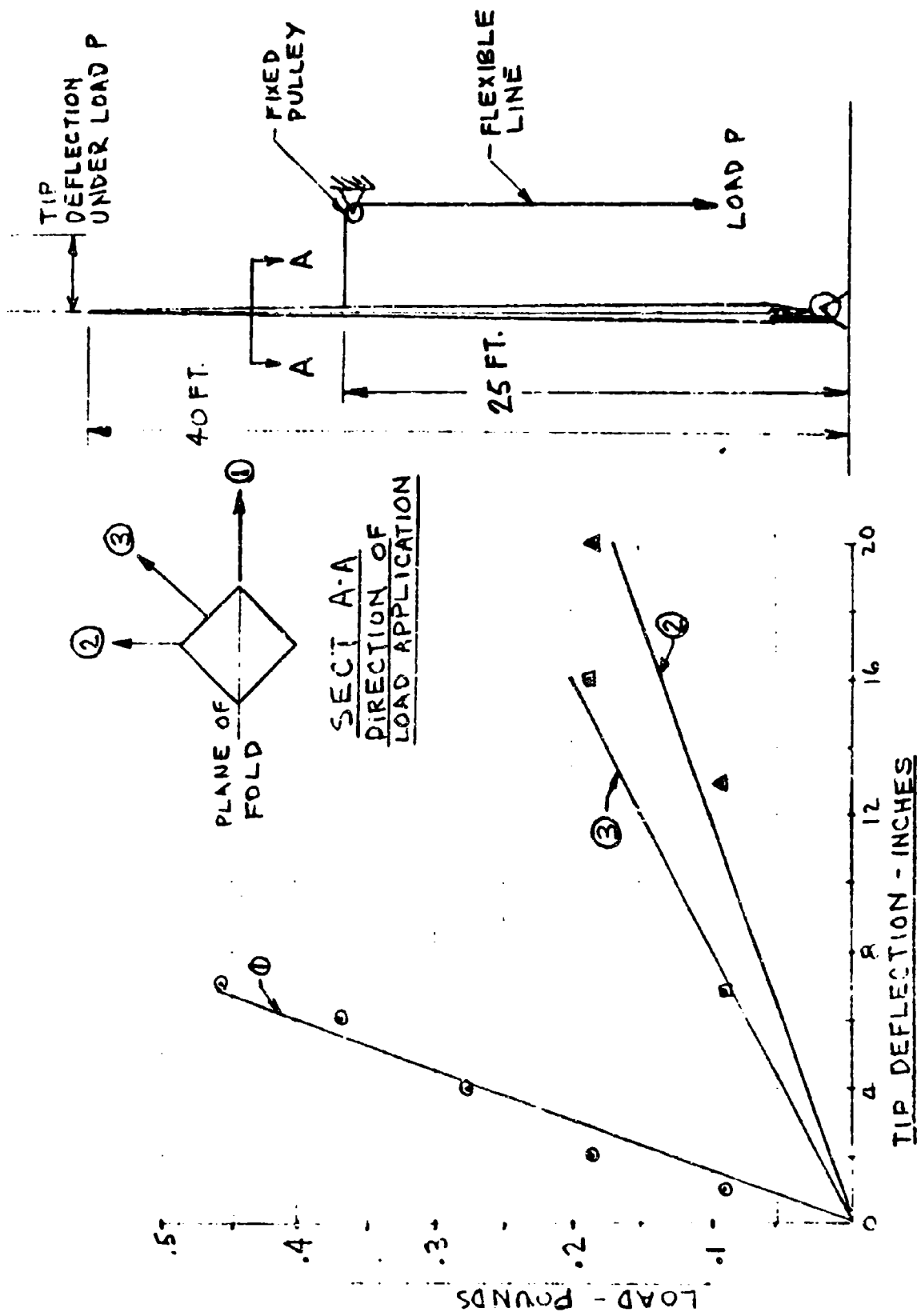


FIGURE 24. CANTILEVER LOAD TEST

SECTION V

OPERATING PROCEDURES

The following procedures should be used in operating the General Electric Roll Up Antenna Mast Model GTA-2:

1. Remove the outer cover leaving it attached to one side of the stand.
2. Remove the ratchet extension handle from the upper support frame.
3. Rotate the upper support frame into erected position as shown in Figure 26 and lock in place with thumb screws as shown in Figure 27.
4. Place stand under point in trees through which the mast will be raised. The upper support frame should be on the operator's right with the ratchet away from him.
5. Remove retaining belt.
6. Hold stand stationary by placing feet on lower flanges of support frame. Raise mast by pulling from reel as shown in Figure 28. Hands should grasp mast as shown in Figure 29 with pressure applied on vertical rods. Do not lift mast by hooking fingers between diagonals since excessive force applied to the center of the diagonals could cause damage.
7. After 70 or 80 feet of mast have been pulled from the reel, the load will become excessive. At this point, hold the mast in the elevated position with the right hand and unwind several turns from reel with left hand as shown in Figure 30.

8. When desired height is reached, lock mast in place by engaging hook at base of diagonal member as shown in Figure 31.
9. To retract mast, put ratchet extension handle in place. The ratchet arm may have to be rotated to a convenient location by reverse rotation of the ratchet or by rotating the storage reel.
10. Unhook the mast lock and support the mast with the right hand while operating ratchet with left as shown in Figure 32. To maintain tight wrap of the mast on the reel some upward force should be applied to the mast.
11. After left hand has reached upper support, transfer hand to higher position as shown in Figure 33. Repeat ratcheting until mast is retracted to top of support frame as shown in Figure 27.
12. Replace retaining belt.
13. Loosen thumb screw, fold upper support frame and hook end of mast as shown in Figure 25.
14. Replace cover, tying securely to holes in lower flange.

The fiberglass rods, particularly at the largest mast section, contain considerable stored energy that tries to unwrap the mast from the reel. A friction brake is provided on the drum to resist this unwrapping torque. The slip torque can be adjusted by changing the shims between the brake leaf and the frame. If the torque changes significantly, the brake should be disassembled and inspected to see that it is clean.

To minimize wear on the mast joints, be sure the teflon rollers are free turning.

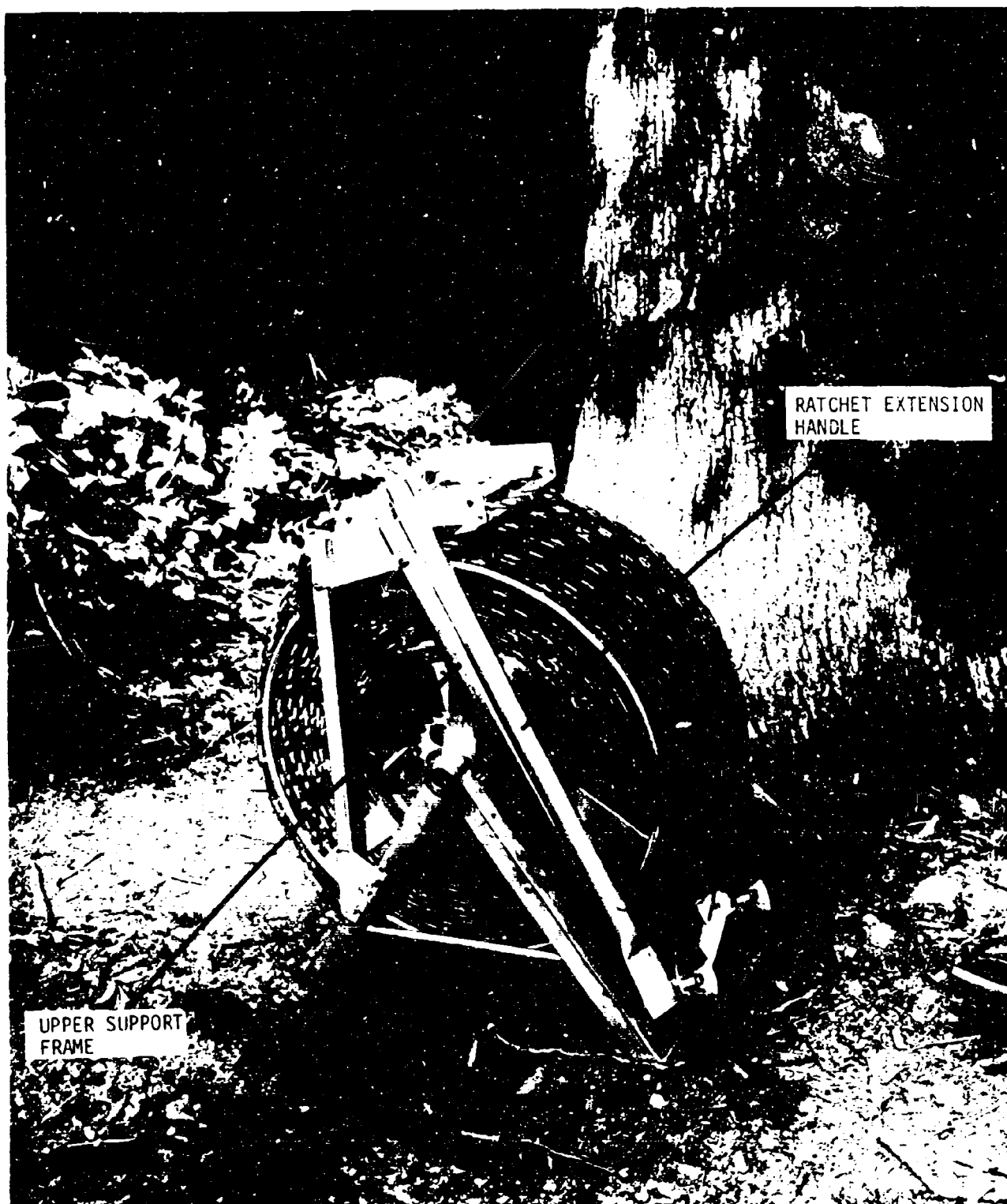


FIGURE 25

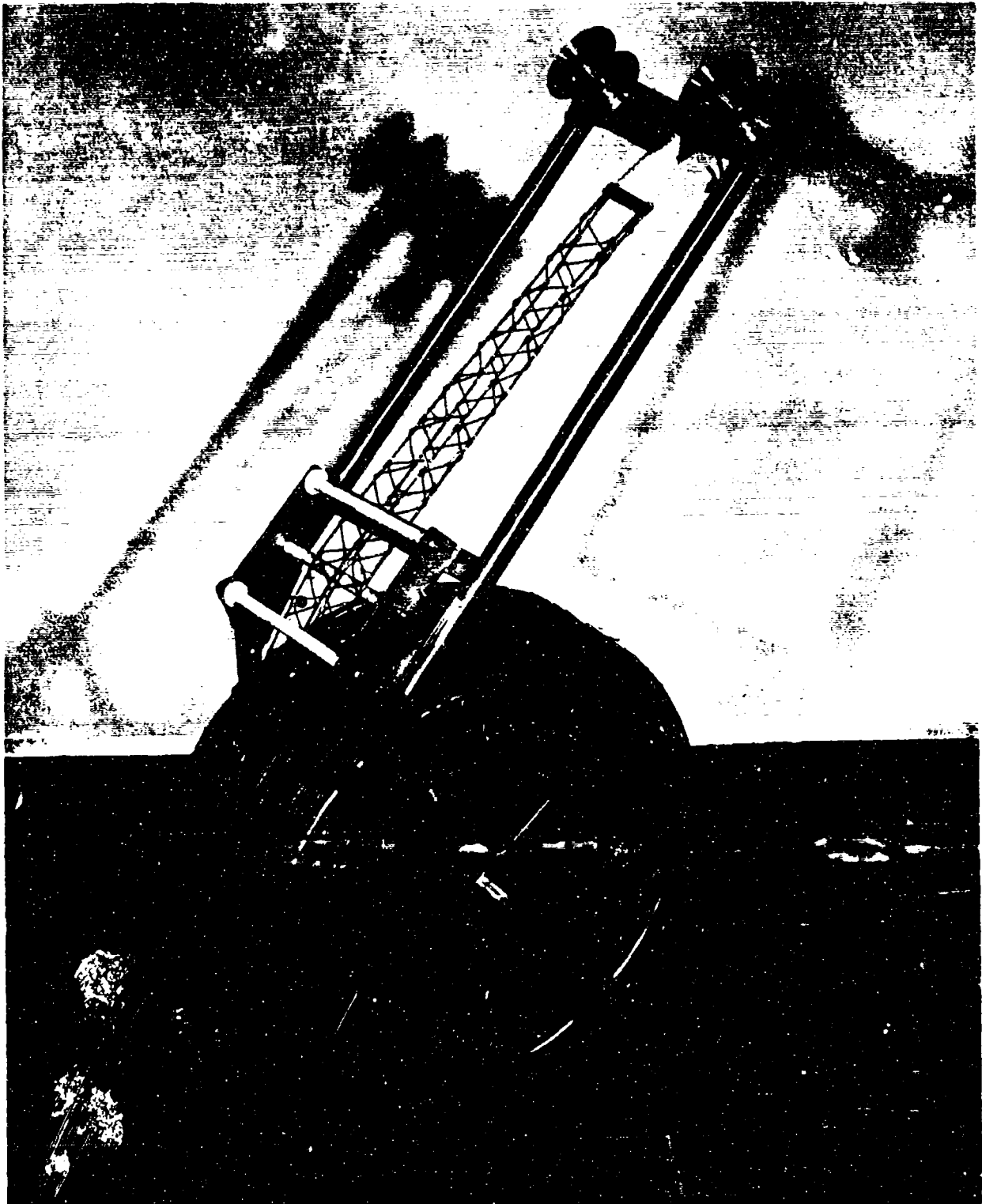


FIGURE 20

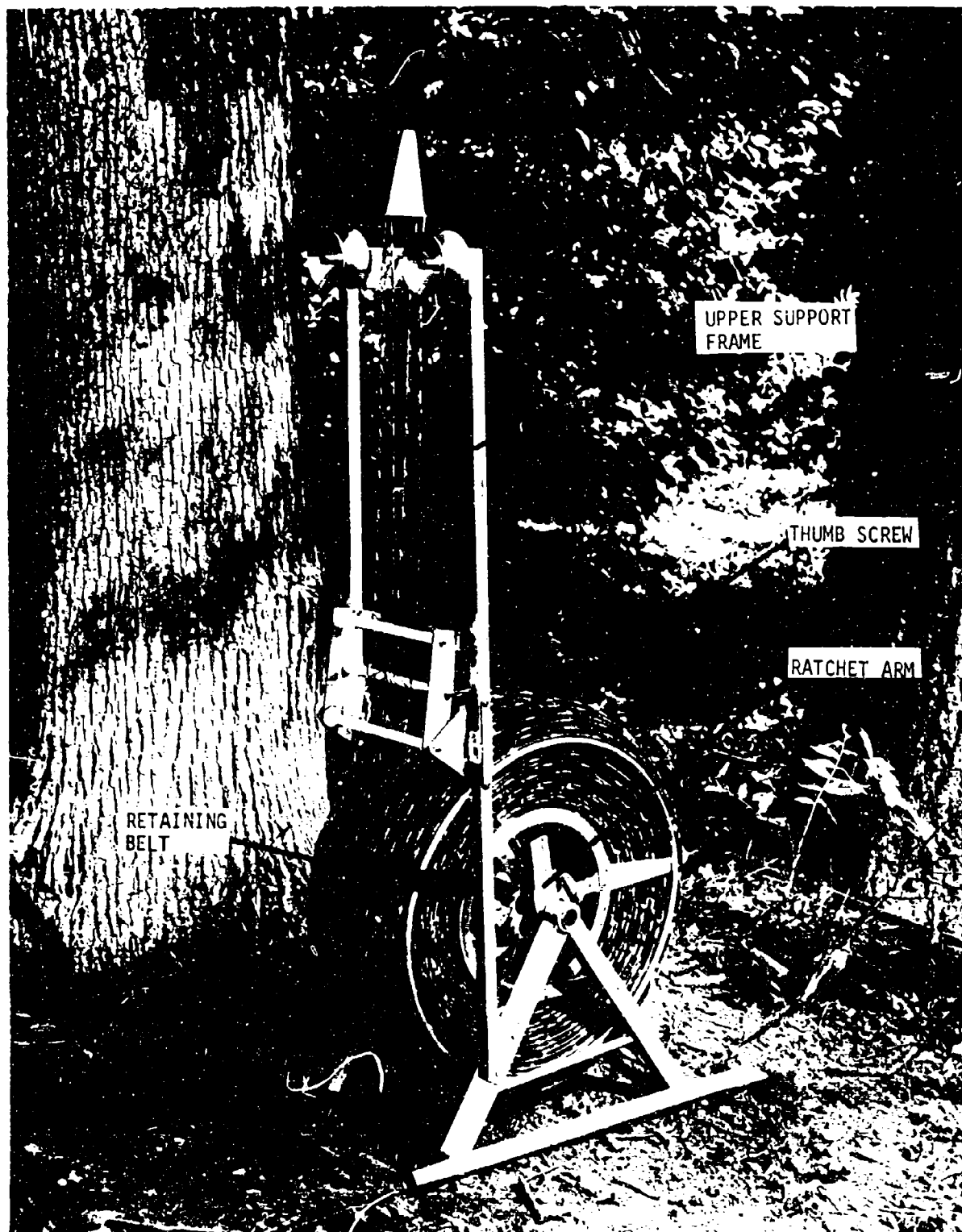


FIGURE 27

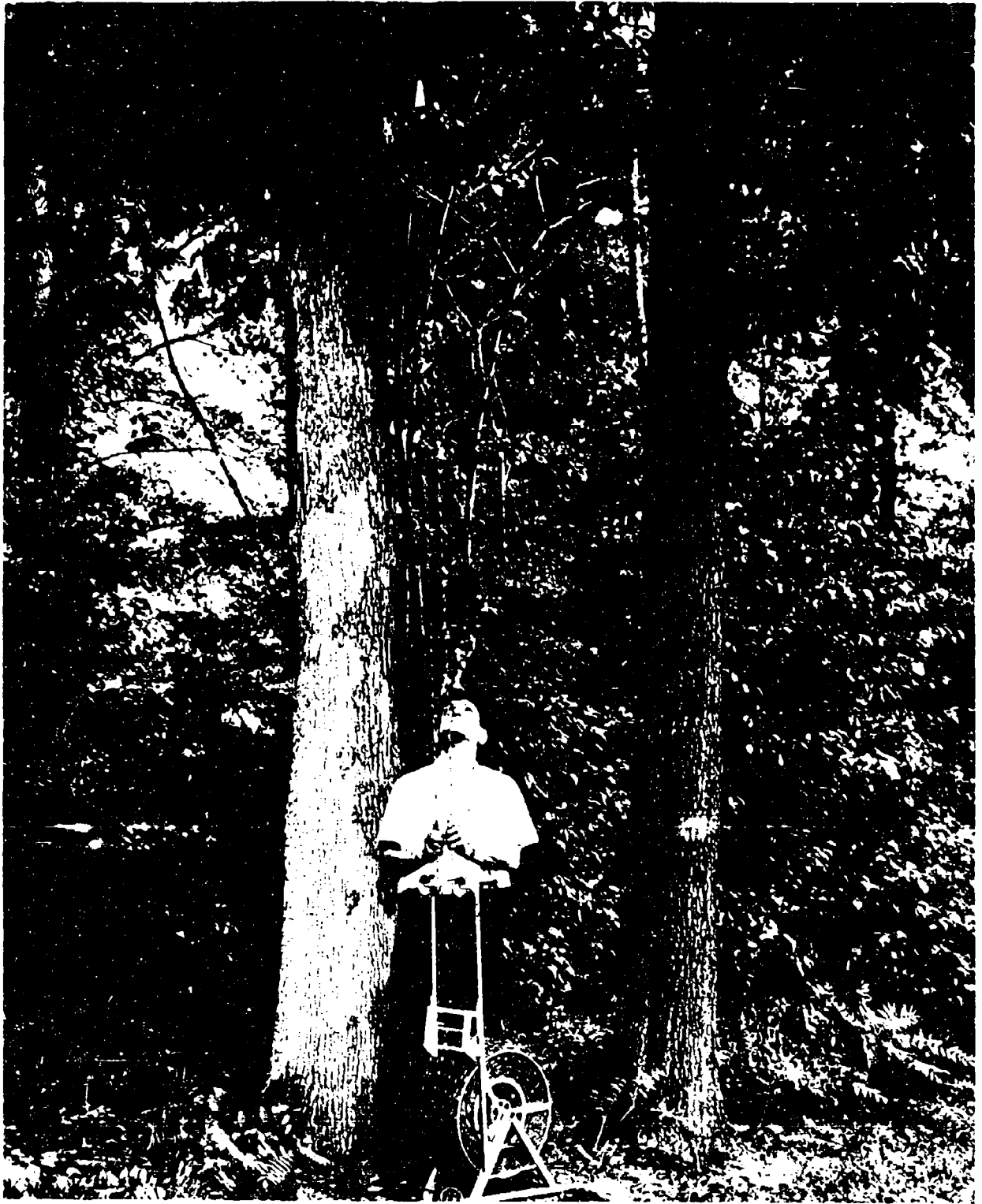


FIGURE 28



FIGURE 29

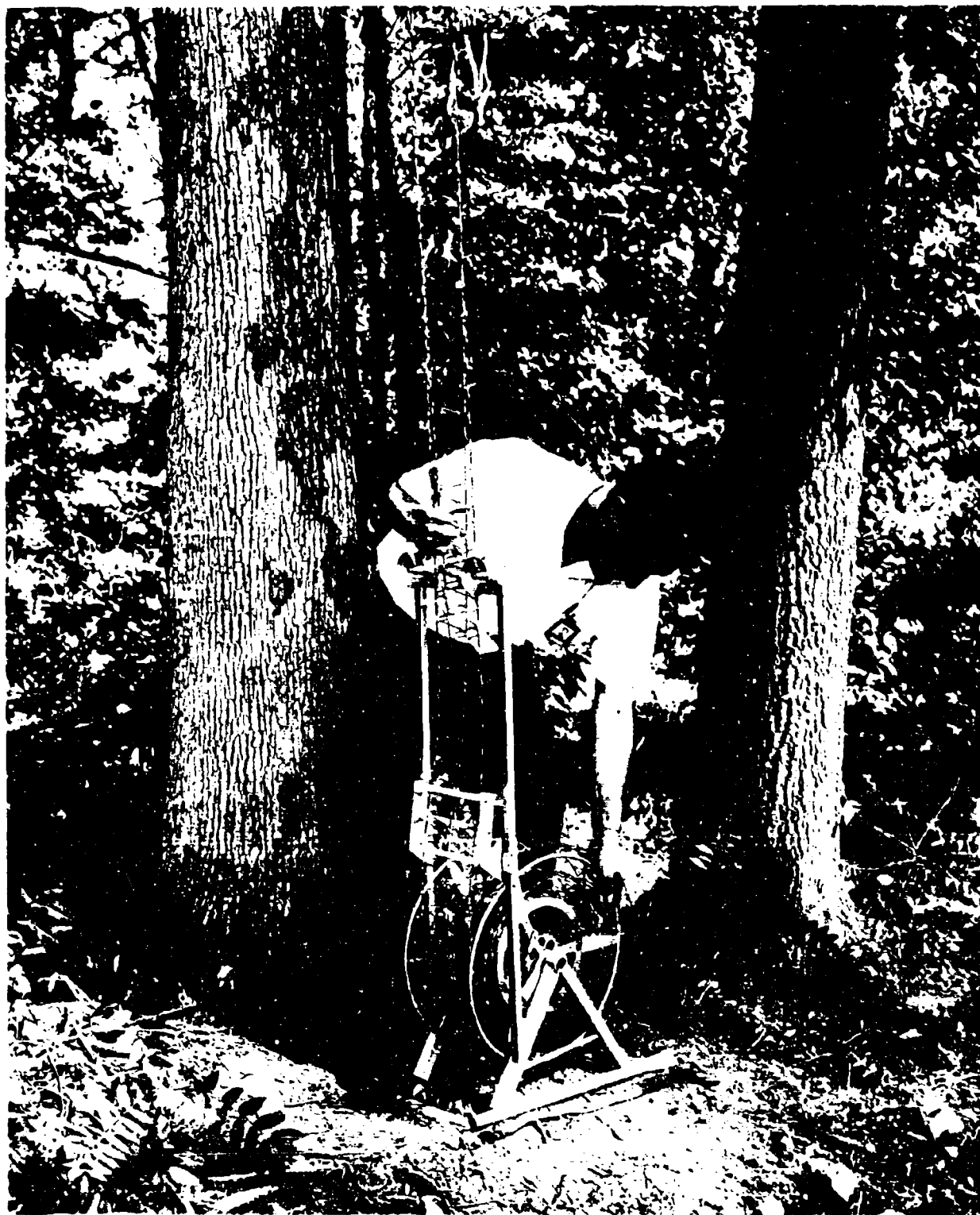


FIGURE 30

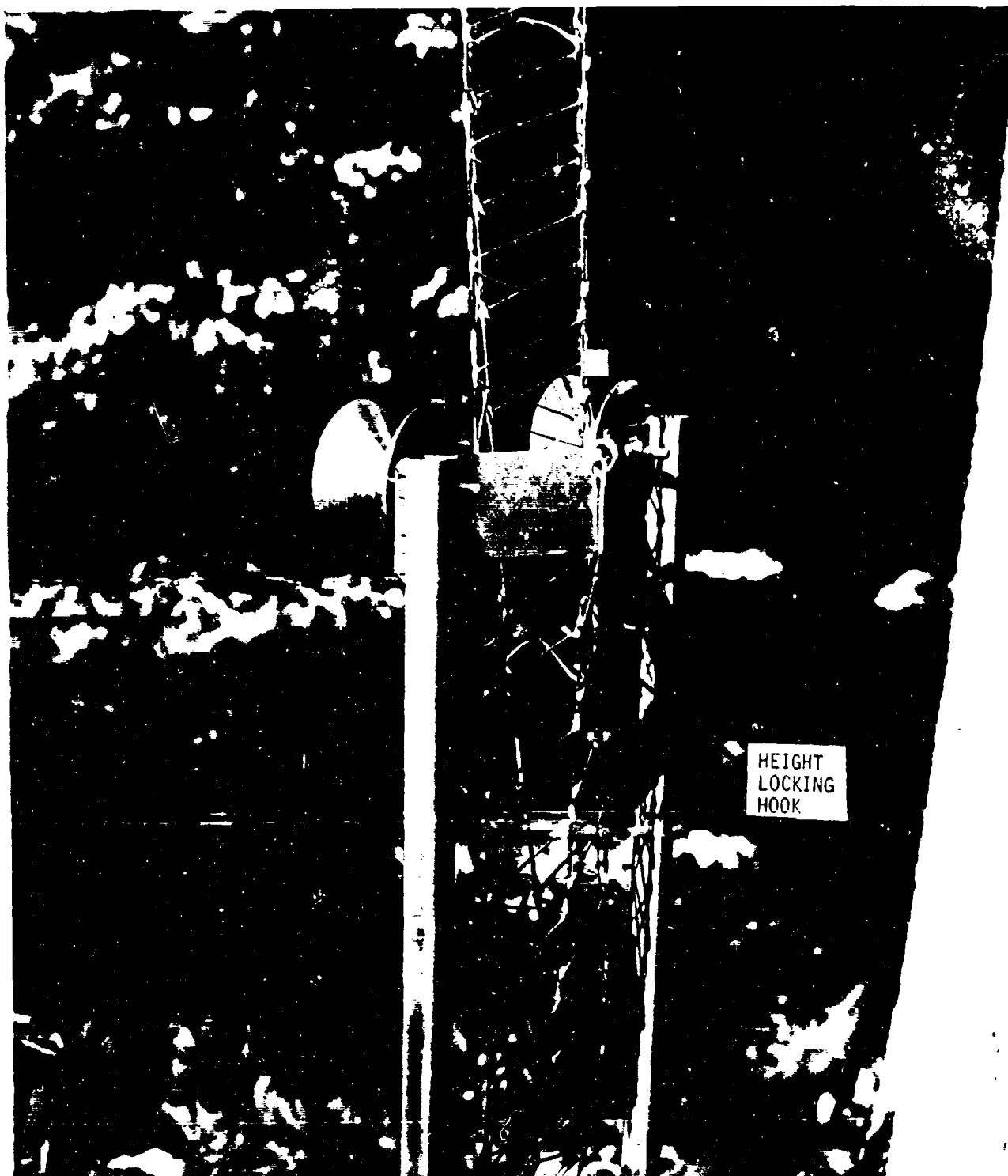


FIGURE 31



RATCHET
EXTENSION
HANDLE

FIGURE 32



FIGURE33